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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1956 MARCH MEETING

AT

PITTSBURGH, PENNSYLVANIA

March 15–17, 1956

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1956 MARCH MEETING AT PITTSBURGH, MARCH 15–17, 1956

THE **1956 March meeting of the American Physical Society** will be held in Pittsburgh, Pennsylvania, on Thursday, Friday, and Saturday, the fifteenth, sixteenth, and seventeenth of the month. (A surprising number of our members have been marking their abstracts for the "Pittsburg" meeting: hereby they are told that such a spelling irritates a Pittsburgher almost as much as "Frisco" infuriates a San Franciscan.) This will be the eighth of our March meetings and the second of them held in Pittsburgh. It is only five years since last we assembled in the metropolis of Western Pennsylvania, and yet the contributed papers at that meeting numbered only sixty-two as against the more than two hundred of the present. Further, the balance of the programme has shifted, or rather has vanished. Where in 1949 we had nearly as many ten-minute papers outside of solid-state physics as in it and high-polymer physics was not represented, we now find that the Division of High-Polymer Physics and the Division of Solid-State Physics have established almost a monopoly. There being only a single session of contributed papers in which all of the other fields are mingled (strange bedfellows!), it is clear that the physicists of these other fields are abandoning the March meeting and bringing about the consummation that was apprehended by some and desired by others when this convention was added to the calendar of the year.

The Chairman of the Local Committee is David Halliday of the University of Pittsburgh, to whom and to whose colleagues we shall owe a great debt. The scientific sessions will be distributed between the University of Pittsburgh and the Mellon Institute on Thursday and Friday and will be concentrated at the Carnegie Institute of Technology on Saturday.

Hotel rooms have been booked for our members in the Webster Hall Hotel (singles without bath $4.25, singles with bath $7.50 to $9, doubles with bath $10, $12, and $15) and at the Schenley Park (singles $7 to $13.50, doubles $10 to $17.50). Write immediately to the hotel of your choice, mentioning that you are coming to our meeting. These hotels are in the neighborhood of the three institutions aforenamed. If their supply of rooms is exhausted long before the meeting itself, they will provide rooms in other hotels; this cannot be guaranteed for last-minute reservations. The East Liberty station of the Pennsylvania Railroad is the most convenient to all.

The **registration desk** will be in the Mellon Institute. Here tickets for the banquet will be sold, and there will be nearby blackboards to carry announcements of messages, of post-deadline papers, and of last-minute changes in arrangements. The registration fee will be one dollar.

Our **Division of High-Polymer Physics** provides three sessions, one on each of the first three half-days of the meeting, consisting mainly of ten-minute papers but with one invited paper at each of the first two. Note that its Business Meeting will be held on Thursday afternoon.

Our **Division of Solid-State Physics** has provided four half-day sessions of invited papers. The first (in order of time) is diversified, the second is entitled Low-Temperature Physics, the third carries the name Luminescence, and the fourth pertains to Semiconductors. J. G. Daunt and C. C. Klick are the organizers of the second and the third.

The **Oliver E. Buckley lecture** will be given on Saturday morning by the latest (1956) winner of the Oliver E. Buckley Solid-State Physics Prize, whose name is now published for the first time (in this connection): he is Clifford G. Shull, and the title of his lecture is "Magnetic crystallography by neutron-diffraction."

Other invited papers comprise two in ferromagnetism (by F. Keffer and H. Suhl); two on a topic which spans the border between elementary-particle physics and solid-state physics (S. de Bene-

detti and L. A. Page). Three—those of T. H. Fields, R. T. Siegel, and L. Wolfenstein—lie wholly in the domain of nuclear physics: the Secretary is not sure that he has done these speakers a favor by inviting them, but it is good to have nuclear physics represented even at this meeting and even though by few.

Two hundred and twenty-four contributed papers are distributed among twenty-one sessions. Last year's total was 201. After three years of near-stability, the number has risen. The Society and the Secretary owe much to J. A. Burton and S. L. Quimby for advising in the arrangement of the ten-minute papers in semiconductors and metals, respectively.

The **Banquet of the Society** will be held on Friday evening in the Webster Hall Hotel. Here the Oliver E. Buckley Solid-State Physics Prize will be conferred on C. G. Shull. The after-dinner speakers will be P. D. Foote and H. Mark. Tickets will be on sale at the registration desk. If at all possible, please buy your tickets before 2:00 P.M. on Thursday; the number available thereafter will be very limited. If not sure that you can reach the desk by 2:00 P.M. on Thursday, better send your check with the form on page 155 of this Bulletin. The price of a ticket will be four dollars.

Post-deadline ten-minute papers pertaining to very recent achievements of very special importance will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society (the address below) not later than Friday, March 9. Papers which missed the deadline by just a couple of days are not eligible for this privilege. The names of such papers as may be accepted will be written on a blackboard near the registration desk, and the papers will have opportunity of presentation under the ten-minute rule at the end of Session G. The abstracts will not be published.

The Council of the American Physical Society will meet at 4:30 P.M. on Thursday at a place of which its members will be informed by special notice.

For the calendar of prospective meetings and deadlines for the remainder of 1956, see page 107 of this Bulletin. Here are printed also the rules for the preparation of abstracts. Please abide by them, including those against abstracts spread over two pages, abstracts broken into paragraphs, carbon copies, and very thin paper. Violation of these rules causes much trouble and some expense to the editors. For the (second) announcement of the 1956 Spring Meeting, see below.

This is the third issue of the Bulletin in its new form with its new significance as the sole repository of the abstracts of ten-minute papers, which abstracts are not now being republished in *The Physical Review*. Errata will be published in a subsequent issue of this Bulletin if received not later than three weeks after the distribution of this issue.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Second Announcement of the 1956 Washington Meeting

The **1956 Spring Meeting of the American Physical Society** will be held at Washington, D. C., on Thursday, Friday, and Saturday, **April 26, 27, and 28.** The Sheraton-Park Hotel will function as Central Reservation Bureau, and all requests for rooms should be sent to its Reservation Office for distribution among the Sheraton-Park, Shoreham, and Windsor Park Hotels and the Hotel 2400. We quote from the message of its Sales Manager: "April is a very busy month for all Washington hotels, and it is requested that your members make their reservations early. All hotels concerned would be able to handle more of your members if they would share rooms with other members. This would also enable each member to have a more economical rate." Do not forget to mention this Society when making your reservation!

Deadline is Friday, February seventeenth.

Attention is directed to the deadlines for the June meetings announced on page 107

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE REMAINDER OF 1956

Place	*Meeting dates*	*Deadline date*
Houston	February 24–25	past
Pittsburgh	March 15–17	past
Washington	April 26–28	February 17
Eugene*	June 21–23	April 20
New Haven	June 21–23	April 27
Chicago	November 23–24	September 21
Monterey*	December	October 19

* Abstracts for the Eugene and Monterey meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past.

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

EPITOME OF THE 1956 PITTSBURGH MEETING

(Personal names are those of invited speakers. Abbreviations: DHPP for Division of High-Polymer Physics, DSSP for Division of Solid-State Physics, CIT for Carnegie Institute of Technology.)

Thursday Morning

A. DHPP: Norberg; high-polymer physics. Mellon Auditorium.
B. Semiconductor compounds. 132 Cathedral.
C. Luminescence. Mellon Conference.
D. Conduction in metals. Mellon Social.
DA. De Benedetti, Page. Stephen Foster Social.

Thursday Afternoon

E. DSSP: Lewis, Dyson, Overhauser, Slichter. Mellon Auditorium.
F. Phenomena of magnetism. Mellon Conference.
G. Siegel, Wolfenstein, Fields; post-deadline papers, if any. Mellon Social.
GA. Carbon and other semiconductors. 8 Cathedral.
H. DHPP: Ivey; high-polymer physics. Business Meeting, DHPP. 132 Cathedral.

Friday Morning

J. DHPP: high-polymer physics. 132 Cathedral.
K. Nuclear magnetic resonance, paramagnetic resonance, ferromagnetic resonance. Mellon Auditorium.
L. Various topics in semiconductor physics. Mellon Social.
LA. Irradiation effects on metals. Mellon Conference.
M. DSSP: low-temperature physics: Garfunkel, Pippard, Friedberg, Heer. Stephen Foster Auditorium.

Friday Afternoon

N. DSSP: luminescence: Williams, Haynes, Dexter, Klick, Bube. Stephen Foster Auditorium.
P. Ferroelectricity; ferromagnetism, I. 132 Cathedral.
Q. General physics. Mellon conference.
R. Irradiation effects on nonmetals. Mellon Social.
S. Various topics in metal physics. Stephen Foster Social.

Friday Evening at Seven

Banquet of American Physical Society. Foote, Mark. Georgian Room, Webster Hall Hotel.

Saturday Morning

T. Mechanical properties of solids. CIT, 2315 Engineering.
U. Buckley lecture (Shull); Keffer, Suhl. CIT, 2210 Enginering.
UA. Solid-state theory. CIT, Industrial Administration.
V. Surface phenomena and diffusion in semiconductors. CIT, 100 Porter.

Saturday Afternoon

W. DSSP: semiconductors: Adams, Fritzsche, Glicksman, Bond. Business meeting, DSSP. CIT, 2210 Engineering.
X. Order-disorder phenomena. CIT, Industrial Administration.
Y. Ferromagnetism, II. CIT, 2315 Engineering.
Z. Diffusion in metals. CIT, 100 Porter.

PROGRAMME

THURSDAY MORNING AT 10:00

Mellon Institute Auditorium

(R. S. MARVIN presiding)

First Session of DHPP

Invited Paper

A1. Pulsed Nuclear Magnetic Resonance in Polymers. R. E. NORBERG, *Washington University.* (40 min.)

Contributed Papers

A2. Effects of Molecular Weight and Solvent Viscosity upon Proton Magnetic Resonance Relaxation in Polymer Solutions.* A. W. NOLLE, *The University of Texas.*—It was shown previously[1] that the proton magnetic resonance relaxation times for dilute CCl_4 solutions of polyisobutylene are about 70 millisec, independent of concentration. In further experiments, the molecular weight has been varied between 1700 and 2×10^6, and the solvent viscosity has been varied by control of temperature and pressure. The dilute-solution relaxation times are nearly independent of molecular weight, in agreement with previous indications that the behavior is governed by the reordering time for small segments of the polymer molecule. The critical concentration, where molecular interaction begins, decreases with increasing molecular weight, in agreement (at higher molecular weights) with the statistical formula for effective molecular radius. The temperature variation of the relaxation times is explained by the behavior of the solvent viscosity, but the variation with pressure (a decrease by a factor of 2 at 1000 atmospheres, 25°C) is somewhat less than that predicted from the solvent viscosity. Similar results are obtained for polystyrene CCl_4 solutions, for which the relaxation times are about one-third of those for polyisobutylene.

* Supported by the Office of Naval Research.
[1] A. W. Nolle, Phys. Rev. **98**, 1560 (1955).

A3. Polarization of Scattered Light from Oriented Polyethylene.* FORREST H. NORRIS AND RICHARD S. STEIN, *University of Massachusetts.*—The polarization of visible light scattered from oriented polyethylene films has been observed using polarized incident light. The effect of degree of elongation of the film, orientation angle, and scattering angle have been observed. Results have been correlated with those obtained by x-ray diffraction and birefringence. The scattering unit is electrically anisotropic and appears to have its greatest polarizability in a direction making a small angle with the greatest dimension of the unit. On elongation, this direction is brought parallel to the direction of stretching. The loss of randomness of orientation on stretching contributes to the decrease in intensity of scattering. A model has been adopted which involves, as parameters, the angle ϵ between the C-crystallographic axis and the stretching direction and the polarizabilities α_1 and α_2 parallel and perpendicular to this direction. Using the value of ϵ' calculated from x-ray data, α_1 and α_2 may be calculated from light-scattering results. The relationship between these values and the structure of polyethylene is discussed.

* Supported in part by a contract with the Office of Naval Research.

A4. Depolarization of Light Scattered by Stiff Chains. MARTIN GOLDSTEIN, *Mellon Institute.*—The intensity (symbolized by H_v) of the horizontal component of light scattered by chain molecules from a vertically polarized incident beam gives information about the correlation in direction between the optic axes of different elements.[1] If there is correlation between elements whose distance apart is appreciable compared to the wavelength of the light, H_v depends on the scattering angle θ. Using a recently developed equation for scattering by anisotropic systems,[2] certain methods and equations used in the study of the statistics of stiff chains,[3] and an approximation replacing the average of certain products of molecular configurational parameters by the product of averages, the initial dependence of H_v on θ is found. The results are expressed in terms of the contour length and "persistence length"[4] of the molecule.

[1] H. Benoit, Compt. rend. **236**, 687 (1953).
[2] M. Goldstein and E. R. Michalik, J. Appl. Phys. **26**, 1450 (1955).
[3] G. Porod, J. Polymer Sci. **10**, 157 (1953).
[4] G. Porod, Monatsh. Chem. **80**, 251 (1949).

A5. Infrared Spectrum and the Structure of Polyvinyl Chloride. S. KRIMM AND C. Y. LIANG,* *University of Michigan.*—A structure has been suggested[1] for polyvinyl chloride which contains two monomer units in the fiber axis repeat and is consistent with x-ray diffraction studies. We have attempted a complete assignment of the bands in the infrared spectrum on the basis of this structure. We have obtained the spectrum in the region of about 3000 cm^{-1} to 70 cm^{-1}, the polarized spectrum being obtained down to about 350 cm^{-1}. The analysis was performed with the help of group theory, calculations of skeletal frequencies in long chain molecules, and a comparison with the spectra of analogous small molecules. A very satisfactory set of assignments is proposed, which implies that the assumed structure is most likely the correct one.

* Present Address: American Viscose Corporation, Marcus Hook, Pennsylvania.
[1] C. S. Fuller, Chem. Revs. **26**, 143 (1940).

A6. On the Detailed Structure of Poly-(*p*-Chlorostyrene-Styrene) Copolymers.* RICHARD N. WORK, *Princeton University.*—Using Onsager's internal field, an expression has been developed which relates the dipole orientational contribution to the dielectric constant $\epsilon_s-\epsilon_\infty$ to the effective mean-square dipole moment and the concentration of each of the polar components in polar-polar or polar-nonpolar copolymers. Following Kirkwood, the effective mean-square dipole moment of each polar group in the chain is expressed in terms of the moment of an equivalent isolated group, the fractions of $A-A$, $A-B$, and $B-B$ pairs of nearest neighbors in the chain (which can be calculated from the average composition and the monomer reactivity ratios), and the average cosines of the angles between the vectors that represent the polar groups in each of these pairs. Except for nearest neighbors along the

chain, effects of short-range forces leading to angular correlations of dipoles have been neglected. The three average cosines have been calculated using experimental values of $\epsilon_s - \epsilon_\infty$ for several copolymers of *p*-chlorostyrene and styrene covering the whole range of composition. A curve of the sum of the two effective mean-square moments, weighted according to their concentration, *vs* composition calculated from these values agrees with all of the experimental points within experimental error.

* Supported jointly by the Army and Navy under Signal Corps Contract DA-36-039SC-42633.

A7. Melting Temperatures of Undeformed Natural Rubber Vulcanizates. DONALD E. ROBERTS AND LEO MANDELKERN, *National Bureau of Standards.*—The melting temperatures of two series of natural rubber gum vulcanizates, each series containing varying concentrations of cross links, were determined using dilatometric techniques. In one series cross linking was accomplished by reaction with di-tert butyl peroxide while in the other series a sulfur-accelerator mixture was used. Crystallinity was induced in the polymers solely by cooling and the subsequent heating was carried out extremely slowly so that equilibrium conditions could be approached. In treating the melting of cross-linked polymers it can be supposed that they behave as random copolymers, since the units participating in the cross linkages will be structurally different from the other units and hence should act as a foreign noncrystallizing component. From such considerations it is predicted that the melting temperatures of natural rubber vulcanizates should only be negligibly different from the unvulcanized polymer. However, the experimental results for both series of rubbers indicate quite conclusively that an appreciable depression of the melting point is achieved on cross linking. For example the melting temperature of a 2% sulfur vulcanizate is 25°C lower than that of unvulcanized natural rubber. It is concluded that a greater disruption of the chain units occurs than is indicated solely by the final amount of cross linking present.

A8. Dielectric Properties of Polychlorotrifluoroethylene (Kel-F). JOHN D. HOFFMAN AND ARNOLD H. SCOTT.—The dielectric constant and dielectric loss factor of polychlorotrifluoroethylene have been measured between 5×10^1 and 10^7 cycles per second at temperatures ranging from −40°C to +100°C. Both amorphous and highly crystalline specimens were studied. The loss data indicate that there is a considerable amount of orientational freedom in the crystalline regions of the polymer.

THURSDAY MORNING AT 10:00

132 Cathedral of Learning

(J. R. HAYNES presiding)

Semiconductor Compounds

B1. Preparation and Characteristics of Zinc Telluride Crystals. EDWARD L. LIND AND RICHARD H. BUBE, *RCA Laboratories.*—Zinc telluride crystals have been grown from the vapor phase and from the following melts (slow cooled in a temperature gradient in a sealed quartz tube): (1) solution of zinc telluride in zinc, (2) solution of zinc telluride in tellurium, and (3) a melt of zinc telluride. All of the crystals prepared to date show *p*-type conductivity; particular care is required to minimize *p*-type copper impurity contamination during the high-temperature crystal growth. High conductivity crystals showing carrier concentration of about 10^{17} per cm³ and hole mobility of about 7 cm²/volt sec have been prepared with the deliberate incorporation of copper impurity. Insulating crystals with room temperature resistivity of 10^{11} ohm-cm have been prepared by compensating residual copper impurity with incorporated *n*-type aluminum or indium impurity. Absorption spectra and photoconductivity excitation spectra indicate a band gap of about 2.1 ev. Crystals prepared with copper added to the melt show an additional absorption band with maximum at 0.6 ev. Ohmic contacts to the crystals have been made with both indium metal and silver paste electrodes. Measurements of the rectification direction using one ohmic and one point-contact electrode indicate that holes are the photocurrent carriers as well as the dark current carriers.

B2. Photoconductivity Phenomena in Zinc Telluride Crystals. RICHARD H. BUBE AND EDWARD L. LIND, *RCA Laboratories.*—The photoconductivity phenomena of temperature dependence, variation of photosensitivity with light intensity, infrared quenching, and thermal stimulation of current in zinc telluride crystals may be correlated through the use of the steady-state Fermi-level analysis with results very similar to those previously found for cadmium sulfide and cadmium selenide crystals.[1] The *p*-type photocurrent in ZnTe:Cu:Al crystals increases exponentially with temperature (between −190° and −50°C) and then reaches a constant value above 25°C; such a temperature dependence can be explained in terms of the effect of a high density of shallow trapping levels according to the model of Rose.[2] The *p*-type photocurrent in ZnTe:Cu:In crystals behaves in a similar manner below −100°C, but, at a temperature corresponding to the location of the Fermi-level at 0.3 ev above the valence band, the photosensitivity abruptly decreases with increasing temperature to about 50°C (corresponding to a Fermi-level 0.65 ev above the valence band). In both types of crystal a close correlation is found between the variation of photosensitivity with light intensity, as a function of temperature, and the temperature dependence of the photosensitivity. In agreement with the theoretical expectations, infrared quenching is found at room temperature for ZnTe:Cu:Al but not for ZnTe:Cu:In.

[1] R. H. Bube, Phys. Rev. **99**, 1105 (1955).
[2] A. Rose, RCA Rev. **12**, 362 (1951).

B3. Photoconductivity Quenching in Cadmium Sulfide.* SIMPEI TUTIHASI, *University of Rochester.*—The temperature dependence of infrared quenching[1] and stimulation of photocurrent in CdS crystals has been investigated in the range −180° to +30°C. Quenching by 1.4μ radiation ceases below ∼−75° while quenching at 0.9μ persists down to −180°, implying that the former is a discrete transition requiring appreciable thermal energy for the release of a trapped hole, while the latter may represent a direct ionization, possibly from the same center. These results are similar to those reported independently by Bube.[2] Stimulation at these wavelengths occurs only at low temperature; the temperature dependence of stimulation at 1.4μ can be observed independently of quenching and indicates that the electron levels responsible are characterized by a thermal trap depth of the

order of half the optical transition energy. Addition of copper impurity extends the photoconductivity spectrum so as to obscure the quenching band at 0.9μ but has little effect on quenching at 1.4μ. Thermal and optical current stimulation effects are absent in the copper-doped crystals.

* This research was supported by the United States Air Force, through the Office of Scientific Research of the Air Research and Development Command.
[1] R. Frerichs, Phys. Rev. **72**, 594 (1947); E. A. Taft and M. H. Hebb, J. Opt. Soc. Am. **42**, 249 (1952).
[2] R. H. Bube, Phys. Rev. **99**, 1105 (1955).

B4. p-Type CdS Crystals. D. C. REYNOLDS, L. C. GREENE, R. G. WHEELER, AND R. S. HOGAN, *Air Research and Development Command.*—Crystals of p-type CdS have been produced from the vapor phase,[1] using Cu_2S as an impurity. The Cu_2S was added to the CdS powder prior to crystal growth. The resulting crystals were dark in color; they were relatively large and single, the largest being approximately $1\times1\times1$ cm. The crystals varied in resistivity from $10^4\Omega$ cm to 0.1Ω cm. The sign of the carriers in the various crystals was determined by the sign of the thermoelectric voltage, by the rectification pattern, and by the sign of the Hall voltage. The room temperature Hall effect was measured for one crystal having a resistivity of 0.125Ω cm. This sample was found to have $2.5\pm0.5\times10^{18}$ carriers and a carrier mobility of 20 ± 4 cm^2/v sec.

[1] Czyzak, Craig, McCain, and Reynolds, J. Appl. Phys. **23**, 932 (1952).

B5. Pressure Dependence of the Electrical Properties of Gallium Antimonide.* J. H. TAYLOR, *Morgan State College.*—The pressure dependence of the Hall coefficient, the resistivity, and energy gap have been measured for intrinsic p-type GaSb. The resistivity increases exponentially with increasing pressure for a change of 2000 atmospheres. The increase in Hall coefficient for the above change in pressure was less than one percent. A value of about 4.0×10^{-6} ev/atmosphere at 573°K was found for the shift in energy gap with pressure. The width of the forbidden energy gap at absolute zero was calculated to be 0.76 ev.

* Supported by the Office of Ordnance Research, U. S. Army.

B6. Absorption Edge in Indium Antimonide.* H. Y. FAN AND G. W. GOBELI,† *Purdue University.*—Absorption edge in indium antimonide has been measured. Using sample thicknesses down to 3.3 microns, measurements were carried to a wavelength of 2 microns. In pure, p-type samples the absorption drops sharply at $h\nu_t=0.175$ ev. The absorption coefficient, α, increases as $(h\nu-h\nu_t)^{0.6}$, indicating that direct transitions are involved. A degenerate, n-type sample with 1.06×10^{18} cm^{-3} carriers was also measured. The relation between the absorption edge in this sample and in the p-type sample is in good agreement with the expression of Kaiser and Fan,[1] $(h\nu(\alpha)-E_G)(1+m_e/m_h)^{-1}+kT\ln(\alpha/\alpha_0-1)=\zeta$, where $h\nu(\alpha)$ is taken from n-type curve and α_0 is the absorption coefficient in the p-type sample at the same frequency. The values 0.175 ev and 1.15 are used for E_G and $(1+m_e/m_h)$, respectively. The value obtained for the constant ζ, Fermi level in the n-type sample, corresponds to an electron effective mass $m_e=0.03m$.

* Work supported by a Signal Corps Contract.
† I. B. M. Research Fellow.
[1] W. Kaiser and H. Y. Fan, Phys. Rev. **98**, 966 (1955).

B7. Structure of Liquid InSb.* R. BUSCHERT, I. G. GEIB, AND K. LARK-HOROVITZ, *Purdue University.*—The x-ray scattering curves of liquid InSb for both copper and molybdenum monochromatic radiations have been measured with a krypton proportional counter. The x-rays were incident on a free surface of molten InSb at 540°C (mp 523°C) in a hydrogen atmosphere. The intensity curves were corrected for polarization and absorption. Tin was used as an average atom for computation of the coherent and incoherent scattering curves used in the Fourier analysis. An artificial temperature correction was applied to the Si(S) curve and the integral term in the radial distribution function evaluated on the Purdue digital computer. This function shows peaks at 3.2 A and 6.4 A and indications of peaks at 3.7 A and 4.6 A. The number of nearest neighbors represented by the area under the 3.2 A peak is 5.7, indicating that the tetrahedral structure of solid InSb is not retained. The effects of various artificial temperature corrections and the use of the Finbak method[1] on the resolution of the peaks will be discussed.

* Work supported by a Signal Corps Contract.
[1] C. Finbak, Acta Chem. Scand. **3**, 1279 (1949); **3**, 1293 (1949).

B8. Elastic Constants of InSb and GaSb Single Crystals. H. J. MCSKIMIN, W. L. BOND, G. L. PEARSON, AND H. J. HROSTOWSKI, *Bell Telephone Laboratories.*—The elastic moduli for high-purity InSb and GaSb single crystals have been determined at 25°C by a phase comparison technique employing ultrasonic waves[1] at approximately 50 megacycles per second. The densities were determined from x-ray powder patterns prepared by V. B. Bala. The results are given in Table I where the s constants are computed from the measured c values.

TABLE I.

	InSb	GaSb
a_0 A	6.479 ± 0.001	6.094 ± 0.001
ρ g/cm^3	5.789 ± 0.003	5.619 ± 0.003
c_{11} d/cm^2	$6.717\times10^{11}\pm0.3\%$	$8.849\times10^{11}\pm0.3\%$
c_{12} d/cm^2	$3.665\times10^{11}\pm0.5\%$	$4.037\times10^{11}\pm0.5\%$
c_{44} d/cm^2	$3.018\times10^{11}\pm0.3\%$	$4.325\times10^{11}\pm0.3\%$
s_{11} cm^2/d	2.422×10^{-12}	1.582×10^{-12}
s_{12} cm^2/d	-0.855×10^{-12}	-0.496×10^{-12}
s_{44} cm^2/d	3.313×10^{-12}	2.312×10^{-12}

Temperature variations of the elastic constants of InSb have been reported recently by R. F. Potter[2] who used a composite oscillator technique.

[1] H. J. McSkimin, J. Appl. Phys. **24**, 988 (1953).
[2] R. F. Potter, Bull. Am. Phys. Soc. Ser. II, **1**, 53 (1956).

B9. Photovoltaic Effect in GaAs Diffusion Junctions.* D. A. JENNY, J. J. LOFERSKI, AND P. RAPPAPORT, *RCA Laboratories.*—$P-n$ junctions have been made on n-type GaAs by diffusing Zn, Cd, or Hg from the vapor phase. Decomposition of GaAs and formation of secondary compounds such as the arsenides of the diffusing element complicate the process. We have estimated that the upper limit for the diffusion coefficient for these acceptors is 10^{-12} cm^2 sec^{-1} at 800°C. According to the theory of solar energy conversion,[1] $p-n$ junctions made on GaAs, which has a band gap of 1.35 ev, should be nearer the highest obtainable efficiency than junctions on Si. Furthermore, since the electron mobility is at least four times higher than in Si, conduction losses are reduced in actual GaAs photovoltaic cells, and the attainable efficiency should therefore approach the theoretical efficiency more closely. Measured efficiencies are still well below theory; for sunlight, as high as 6.5% has been obtained at quantum yields of about 0.4. The spectral response of the photovoltaic current shows a cutoff near 1.35 ev in agreement with other measurements of the band gap.

* Work supported in part by the U. S. Army Signal Corps Engineering Laboratory.
[1] J. J. Loferski, Solar Energy Conference, Tucson, Arizona, November 1, 1955 (to be published).

B10. Electrical Properties of Copper Selenide. EDWARD SONDER AND CHARLES R. WHITSETT, *Iowa State College.*—The resistivity and Hall effect of single crystals of Cu_2Se have been measured and some rather strange nonequilibrium phenomena have been noted. P-type samples with carrier densities of about 10^{20}/cc were prepared by melting stoichiometric quantities of the constituents. The resistivity and Hall coefficient have a negative temperature coefficient below 175°K as one would expect for a semiconductor. An anomalous re-

sistance peak was observed near 200°K, when well-annealed samples were cooled from room temperature to 100°K and slowly warmed. This peak was not observed during two repeat runs; however, it reappeared, although smaller in magnitude, after the sample had been annealed at 450°K. The copper in Cu_2Se has an enormous diffusion mobility,[1] and the structure of the compound changes near 373°K.[2] The observed resistivity anomaly seems to be associated with these properties.

[1] H. Reinhold and H. Moehring, Z. Physik. Chem. **38B**, 221 (1938).
[2] W. Borchert, Z. Krist. **106**, 5 (1945).

B11. Lifetime of Minority Carriers in Magnesium Stannide.* MILTON GOTTLIEB, *University of Pennsylvania.*—Measurements of the carrier lifetime on a single crystal of magnesium stannide were carried out at a temperature of about 100°K. Pulsed illumination from a spark gap was allowed to fall on the sample, and the decay of the photovoltage which was produced was observed on an oscilloscope. The photovoltage was present because of the inhomogeneity of the sample. Exact analysis of the shape of the decay curve is difficult, it being neither purely additional, exponential, or hyperbolic. The lifetime measured in this manner is about 20 microseconds. A calculation of the lifetime using data obtained from photoconductivity measurements was performed, and, although there is some uncertainty in the magnitudes of some of the quantities concerned, an order of magnitude of ten microseconds is indicated, in good agreement with the measured value.

* Supported in part by the Office of Naval Research.

THURSDAY MORNING AT 10:00

Mellon Institute Conference Room

(F. E. WILLIAMS presiding)

Luminescence

C1. Oscillator Strengths in the KCl:Tl Phosphor.* R. S. KNOX† AND D. L. DEXTER, *University of Rochester.*—Wave functions calculated by Hartree[1] without exchange are used to compute energy levels and oscillator strengths in the $^{1,3}P_1 - {}^1S_0$ transitions in free Tl†. The results will be compared with measured f-values in the isoelectronic Hg atom and those of the corresponding transitions in the KCl:Tl luminescent center.[2] In our perturbation approximation the ratio g of f (forbidden to f (allowed) is independent of the dipole matrix element and is simply related to the spin-orbit matrix element H_I. Values of H_I and f in Hg indicate that for the free ion the wave functions are too diffuse, i.e., too small at small distances and too large at distances of importance in luminescence theory[3] ($\sim 3a_0$). Implications of the lack of agreement between calculated and observed values of f and g will be discussed with a view to assessing the validity of the usual model for the KCl:Tl center.

* Research supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
† National Science Foundation Predoctoral Fellow.
[1] Douglas, Hartree, and Ruciman, Proc. Cambridge Phil. Soc. **51**, 486 (1955).
[2] W. Koch, Z. Physik. **59**, 378 (1930).
[3] F. E. Williams, J. Chem. Phys. **19**, 457 (1951); J. Phys. Chem. **57**, 780 (1953).

C2. Low Temperature Excitation Spectrum of KCl:Tl. D. A. PATTERSON AND C. C. KLICK.—The excitation spectrum of KCl:Tl has been measured at 77°C in the wavelength range from 2400 A to 2800 A. The data were taken on powder samples ground from the melt in which 0.0004 mole fraction thallium had been added. Excitation bands at 2470 A and 2540 A which produce emissions at 3050 A and 4750 A, respectively have been resolved. Johnson and Williams[1] have extended the configuration coordinate model for KCl:Tl to include a second excited state ($^1P_1°$) crossing near the minimum of the first ($^3P_1°$). The derivation was based on the hypothesis that both emissions can be produced by an absorptive transition to a single state. The present data, which appear to be incompatible with this picture, could be interpreted as arising from two slightly different types of thallium centers.

[1] P. D. Johnson and F. E. Williams, J. Chem. Phys. **20**, 124 (1952).

C3. Luminescence from NaCl.* W. E. SPICER,† *University of Missouri.*—In a previous report[1] on the x-ray induced luminescence from NaCl single crystals, a change in both the intensity and spectral distribution brought about by heat treatment was described. Following heat treatment, strong new bands appeared at 2.45 and 3.5 ev. These bands have now been induced in the heat treated crystals by irradiating x-ray colored crystals with light absorbed at F-centers; thus, apparently establishing that this luminescence is due to electrons falling from the conduction band into lower lying levels. The afterglow following x-irradiation has been followed for about 8 hours. It consisted principally of the bands at 2.45 and 3.5 ev. A semilog plot of the decay consisted of 4 almost parallel straight line regions, each succeeding region having a smaller slope. When the afterglow had decayed away, it could be revived by irradiating the crystal with F-light; 1.95 and 1.63 ev light were observed to quench the afterglow. These data indicate that the afterglow is probably due to thermal release of electrons from traps. There is evidence that F'-centers may serve as traps.

* Supported in part by the Office of Naval Research.
† Now at RCA Laboratories, Princeton, New Jersey.
[1] W. W. Spicer, Phys. Rev. **98**, 824(A) (1954).

C4. Stimulation of Edge Luminescence in CdS at 4°K. JOHN LAMBE AND CLIFFORD KLICK, *United States Naval Research Laboratory.*—There has been considerable discussion in the literature with regard to whether the edge emission (5150 to 5500 A at 77°K) in CdS is the result of a specific center or an exciton recombination. Recently, it was proposed[1] that the emission did occur at a center and further that the emission was due to the recombination of a trapped electron and a free hole. On this basis the following effect should be observed. Let a CdS crystal be irradiated with ultraviolet light at low temperature and then kept in the dark. Electrons should remain trapped in the centers, and in addition it can be shown that holes will be trapped in levels which are about 1 ev above the valence band. If the crystal is then irradiated with 1 ev quanta, free holes should be excited, and these should recombine with trapped electrons and emit edge luminescence. The above experiment was carried out at 77°K and 4°K by observing photoconduction and luminescence. At 77°K, irradiation with 1-ev quanta reduced conductivity, but did not stimulate luminescence. At 4°K, 1-ev quanta reduced the conductivity but also stimulated edge luminescence emission in agreement with the view that the emission occurs at a center.

[1] J. Lambe, Phys. Rev. **98**, 985 (1955).

C5. Electroluminescence of Barium Titanate Single Crystals. GEORGE G. HARMAN, *National Bureau of Standards.*—

Electroluminescence was produced by high-frequency excitation in several single crystals of barium titanate. The effect was measured at frequencies from a few hundred kilocycles to over 400 megacycles and displayed an erratic but generally rising luminous output with frequency. Low-frequency (60-cycle) excitation was attempted, but the necessary high field caused the crystal to fracture at the threshold of luminescence. Both point contacts and area contacts were used, the latter being more stable. These contacts were applied at opposite ends of thin narrow crystals and produced a threshold of luminescence at about 166 v/cm at 40 megacycles. The light emission is yellow in color and occurs at the electrode-crystal interface where higher fields presumably exist. The decay time of luminescence on a typical crystal unit, of capacity $=10\ \mu\mu$f, was less than 5 μsec, which was the limit of the associated measuring equipment. Rapid, though not always reproducible, changes in luminescence intensity occur around the Curie point. The effect did not appear to be sensitive to domain structures.

C6. Contact Electroluminescence. W. LEHMANN, *Westinghouse Electric Corporation* (introduced by H. F. Ivey).—Many powdered phosphors not normally electroluminescent become able to electroluminesce if they are simply mechanically mixed with suitable powders of metals or some nonmetals. The emission is limited to many, more or less bright, spots randomly distributed over the cell area. Evidently all phosphor particles emit which are in intimate contact with particles of the contact substance. No correlation could be found between the brightness of this contact electroluminescence and material properties of the contact substance, but the contact substance particles must have suitable size and shape (sharp edges) and good electrical conductivity. Obviously the contact substance particles act mainly by creating localized regions of high electric field strength near their sharp edges. The dependence of the over-all emission intensity on voltage and frequency is similar to that of ordinary electroluminescent zinc sulfides. The conclusion is drawn that the emission of the latter is also due to the presence of second phases (e.g., ZnO or Cu_2S) incorporated as small segregations inside the phosphor particles. The simple presence of such better conducting segregations inside the poorly conducting phosphor crystals must cause strong nonuniformity of the local electric field and, therefore, a very nonuniform distribution of the local electroluminescent brightness.

C7. Electroluminescent Buildup. C. H. HAAKE, *Westinghouse Electric Corporation* (introduced by E. G. F. Arnott).—The buildup of electroluminescent brightness after application of an alternating electric field was studied under various conditions on zinc sulfide phosphor powders. The buildup at +155°C was found as slow as that at room temperature when the phosphors were quenched with infrared radiation prior to field application. Equilibrium was reached faster after preexcitation with strong ultraviolet radiation and faster yet after electroluminescent preexciation. Variations of the applied field strength had no effect on the buildup time. It required, however, more cycles to reach equilibrium when the frequency was increased, although the actual buildup time decreased. Comparison with the photoluminescent buildup showed only a loose parallelism, inasmuch as electron traps are involved in both cases. The remarkable difference is the almost instantaneous photoluminescent buildup at elevated temperature compared to the slow electroluminescent buildup. This can be understood by inspection of the differential equations which approximately describe the kinetics involved. Photoluminescence is retarded by electron capture in traps, whereas in electroluminescence the retardation is predominantly determined by the time dependence of the excitation process. Traps when previously filled will, however, facilitate the initial excitation process and equilibrium is reached faster.

C8. Energy States and Luminescent Processes in ZnF_2:Mn. PETER D. JOHNSON AND FLOYD L. HUGHES, *General Electric Research Laboratory.*—Single crystals of ZnF_2:Mn have a single symmetrical thermoluminescent peak when excited by monochromatic radiation of wavelength 1800 to 2300 A. Photoconductivity, optical absorption, and excitation spectra indicate that the electron trap is a metastable state of the activator. Excitation occurs first to a higher excited state from which both the emitting and trapping states are accessible. From phosphorescent decay curves obtained at various temperatures, it is determined that transfer to the emitting state is approximately 4 times as probable as transfer to the trapping state, with 1850 A excitation. A monomolecular untrapping mechanism modified by thermally activated retrapping from the long-lived emitting state is in accord with the thermoluminescence. The intensity, I, of glow for this system is

$$I=\alpha N_{10}\frac{Ak_1}{A+k_2}\exp\left[-\frac{1}{\beta}\int_{T0}^{T}\frac{Ak_1}{A+k_2}dT\right],$$

where A is the transition probability for emission, k_1 and k_2, the rates of untrapping and retrapping, respectively, and β, the heating rate. The trap depth is 0.62 ev, activation energy for retrapping, 0.505 ev, and frequency factors $s_1=s_2=5\times10^{13}$ sec^{-1}, approximately the restrahl frequency.

C9. *V*-Centers in Evaporated Alkali Halide Films.* K. J. TEEGARDEN, *University of Rochester.*—*V*-centers have been observed in thin alkali halide films formed at −185°C by simultaneous evaporation of the halide and a halogen onto a fused quartz substrate. In KI or KBr the *V*-bands so produced had the same appearance as those occurring in single crystals after additive coloration or x-irradiation at temperatures above that at which the V_1-band disappears. No V_1-band was observed in the films. However, it was found that the positions and relative heights of the *V*-bands in KI or KBr are independent of the halogen used. Cl_2, Br_2, and I_2 in KI and KBr give the *V*-band structure characteristic of the halide. In the case of NaCl and KCl only Cl_2 gives rise to absorption bands similar to the *V*-bands observed in x-rayed crystals. Br_2 and I_2 produced bands which are not easily identified with any previously reported absorption bands. Again, no V_1-band was observed.

* This work was supported by the United States Air Force through the Office of Scientific Research of the Air Research and Development Command.

C10. Low-Temperature Thermal Resistivity of Ca-Doped KCl Crystals.* GLEN A. SLACK,† *Cornell University.*—The thermal resistivity of "pure" and calcium doped KCl single crystals has been measured between 3 and 25°K using a constant heat flow method and carbon resistance thermometers. Substitutional calcium concentrations up to 2.5×10^{-4} were incorporated into pure KCl crystals during regrowth from the melt. Pure crystals have a minimum resistivity of 0.14 cm-deg/watt at 4.9°K. In doped crystals the values of the temperature and resistivity measured at the resistivity minimum both increase linearly with calcium concentration to 13°K and 0.81 cm-deg/watt for 2.5×10^{-4}. At temperatures above the minimum the resistivity increases linearly with temperature for all crystals, as expected for point imperfections.[1] On the low temperature side the boundary scattering limit of resistivity is reached only for pure crystals. Pure KCl, chemical purity about 10 ppm, has an apparent calcium concentration of 3×10^{-4} as deduced from the linear rate of resistivity increase with calcium concentration. This residual thermal resistivity may be caused by isotope scattering.

* Supported in part by the National Science Foundation.
† Now at General Electric Research Laboratory, Schenectady, New York.
[1] P. G. Klemens, Proc. Roy. Soc. (London) **A208**, 108 (1951).

THURSDAY MORNING AT 10:00

Mellon Institute Social Room

(S. L. QUIMBY presiding)

Conduction in Metals

D1. Electrical Resistivity of Nickel Palladium Alloys. A. I. SCHINDLER, R. J. SMITH, AND E. I. SALKOVITZ, *U. S. Naval Research Laboratory.*—From an analysis of magnetic measurements, Wohlfarth[1] has shown that the number of holes in the d-band (n_d) and consequently the number of electrons in the s-band (n_s) remains equal and constant as Ni is alloyed with Pd. This results in a simplification of the two band descriptions of transport phenomena. One generally has to deal with the intermixing of four unknown parameters n_d, n_s and their respective mobilities. Now however, a separation of charge carriers from mobilities can be made. In order to test these ideas we have begun a series of measurements of transport properties of the Ni-Pd alloy system. To date we have examined the electrical resistivity of the Pd rich side of the system as a function of temperature from 77°K to 320°K. The data at 77°K and 293°K both exhibit the same general behavior. The electrical resistivity increases slowly as Pd is added to Ni, reaches a maximum in the vicinity of 70 at % Pd and then falls rapidly to the pure Pd value. This shape is similar to the appearance of the electrical resistivity *versus* composition curve of the Ag-Pd alloy series. $d\rho/dT$ measurements have also been made and exhibit a gradual rise and then a decline as the Curie temperature is reached.

[1] E. P. Wohlfarth, Proc. Leeds. Phil. Lit. Soc., Sci. Sect. **5**, (2), 89 (1949).

D2. High-Temperature Anneal of Cold-Drawn, Pure Al and Au Wires.* RALPH BRAY, *Purdue University.*—Cold-drawn Al(99.99%) and Au(99.97%) wires (0.02 cm diameter) were annealed in air at various temperatures up to 600°C and 920°C respectively. The resulting changes in electrical resistance were measured at −190°C and 20°C. For Al, the data could be analyzed into two types of resistance changes. The first, $\Delta R_r/R_{20°C}$, corresponded to a decrease in residual resistance due to recovery. The other, $\Delta R_d/R_{20°C}$, was an increase in resistance, attributable to a decrease ($=\Delta A/A_0$) in the effective cross-sectional area of the wires due to oxidation. $\Delta R_r/R_{20°C}$ reached and maintained a constant value of about −0.8% for anneal at $T \geq 300°C$. $\Delta R_d/R_{20°C}$ depended strongly on the temperature and duration of the anneal; for $T \leq 350°C$, it was small and saturated with time. At 450°C, it increased rapidly, as $t^{\frac{1}{2}}$. Oxide layer thicknesses between 110 A and 5000 A were thus measured. The general behavior was consistent with previous[1] oxidation measurements by other techniques. Gold wires gave only residual resistance changes; an anneal curve of complicated shape was obtained.

* This work was performed at the Technische Hogeschool, Kelft, Holland, where the author was an NRC Fellow (1952).
[1] E. A. Gulbransen and W. S. Wysong, J. Phys. & Colloid Chem. **51**, 1087 (1947).

D3. Resistivity Resulting from Stacking Faults in Noble Metals.* F. J. BLATT, F. S. HAM,† AND J. S. KOEHLER, *University of Illinois.*—It is known that dislocations in close-packed lattices appear in the form of extended dislocations.[1] The extra resistivity resulting from full edge and screw dislocations has been calculated previously,[2] and from this that resulting from partial dislocations may be estimated. It has been suggested[3] that the large observed changes in resistivity with cold work, exceeding calculated values, may be due to scattering of conduction electrons by stacking faults which appear between the partial dislocations. We have calculated this scattering by a wave matching procedure using Bloch waves. Making use of reasonable approximations, which will be discussed in detail, the result may be expressed in terms of effective mass parameters calculated by Kambe.[4] Using these values one concludes that stacking faults make negligible contributions to the resistivity of cold worked copper and silver, but may be important in gold. The numerical results are quite sensitive to the effective mass parameters.

* Supported in part by the Office of Naval Research.
† Now at General Electric Research Laboratory.
[1] A. Seeger, *Defects in Crystalline Solids* (1955), p. 328.
[2] S. C. Hunter and F. R. N. Nabarro, Proc. Roy. Soc. (London) **A220**, 542 (1953).
[3] J. S. Koehler, *Impurities and Imperfections*, American Society for Metals, Chicago (1955), p. 162.
[4] K. Kambe, Phys. Rev. **99**, 419 (1955).

D4. Resistivity from Clustered Vacancies in Copper.* D. L. DEXTER, *University of Rochester.*—The excess resistivity and stored energy associated with clusters of vacancies, i.e., cavities, are calculated for copper on the basis of a simple model; the cavities are assumed spherical and shielding effects are neglected so that the results are valid only for clusters of more than about 10^2 vacancies. The evidence for the existence of cavities, the results of the present calculations, and comparison with other scattering entities will be presented, and the implications discussed. It appears probable that, in copper heavily cold worked at nitrogen temperatures, a large fraction, of the order one-half, of the energy expended is stored in the form of vacancies, many of which cluster into cavities upon warming to room temperature. Vacancies formed by radiation damage seem to behave similarly.

* Research supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.

D5. Resistivity Changes in Gold-Cadmium Induced by Quenching. MONROE S. WECHSLER, *Oak Ridge National Laboratory.*—It has been found that large increases in the resistivity of β Au-Cd result from quenching from a high temperature. The amount of quenched-in resistivity was measured as a function of quench temperature yielding an energy of formation of about 0.4 ev for the quenched-in defect. The isothermal decay of the quenched-in resistivity was observed at a number of temperatuers from 60 to 85°C. The activation energy for the motion of the defect was found to be about 0.6 ev. Furthermore the shape of the isothermal annealing curve is sigmoidal, indicative of a two-stage annealing process. The effect is interpreted in terms of the quenching-in of a non-equilibrium number of lattice vacancies. It is estimated on the basis of Jongenburger's[1] calculation for pure gold that 0.7 atomic percent vacancies are frozen in upon quenching from 450°C.

[1] P. Jongenburger, Appl. Sci. Research **B3**, 237 (1953).

D6. Dimensional Changes in Gold-Cadmium Induced by Quenching. W. J. STURM AND M. S. WECHSLER, *Oak Ridge National Laboratory.*—A series of measurements of changes in density and length upon quenching a β Au-Cd specimen were made in a manner analogous to the resistivity measurements of the previous paper. Density decreases up to 0.3% upon quenching were observed, suggesting that the quenched-in defect is a vacancy. The dependence of density decrease upon quench temperature yielded an energy for defect formation of 0.3 ev and resistivity measurements on the same sample

yielded the same value. Upon isothermal anneal the quenched specimen showed a density *versus* time dependence very similar to that determined by measurements of resistivity. The same was true of measurements of change of dimension using strain gauges. A quantitative estimate of the number of vacancies produced is made in terms of an elastic model[1] and yields a value of 0.6% upon quenching from 450°C. This value compares favorably with that determined by electrical resistivity measurement and lends support to the contention that vacancies are responsible for the effects observed.

[1] C. W. Tucker and J. B. Sampson, Acta Metallurgica **2**, 433 (1954).

D7. Brillouin Zone Studies, VII. Thermoelectric Power of Dilute Magnesium Alloys. E. W. KAMMER, E. I. SALKOVITZ, AND A. I SCHINDLER, *U. S. Naval Research Laboratory.*—Experiments reported earlier[1] in this series have shown that the slope of the curve for thermoelectric power as a function of valence electrons per atom, changes sign for those concentrations of the impurity element which induce Brillouin Zone overlap. These results were obtained at room temperature. Since the number of electrons occupying the overlap energy levels is also a function of the temperature, the atomic percent addition of impurity atoms will have to be increased at low temperatures to create the same overlap condition present at a higher temperature. It is found that the precentage addition, a, of the impurity element necessary to produce a change in sign of $d\theta/da$, where θ is the thermoelectric power, has indeed significantly incraesed at 78°K. The atomic percent of indium present for example must be increased from 1.2% at room temperature to 3.0%, neglecting core potential effects. Similarly, the atomic percent of aluminum must also be increased by 1.8% ,from 0.3% at room temperature to 2.1% at liquid nitrogen temperature. Both of these elements raise the valence electrons per atom ratio in the magnesium lattice. For elements which have a valence of two or unity (cadmium, silver, lithium) no change in sign of $d\theta/da$ is observed.

[1] Kammer, Salkovitz, and Schindler, Phys. Rev. **100**, 1257(A) (1955).

D8. Grain Boundaries and Electron Transport Phenomena in Metals. J. S. KOEHLER,* *University of Illinois.*—Consider a material which has nonspherical constant energy surfaces in k-space. The conditions which enable one-electron wave functions appropriate for neighboring grains to be joined at the grain boundary are: first, that the component of k tangential to the grain boundary must be continuous, and second, that the functions must be associated with the same energy. Hence if the energy surfaces appropriate for the two grains are projected on the grain boundary (these are, of course, the same surface but one is rotated with respect to the other) matching can only be done for k-values associated with the region common to the two projections. An electron in a state whose projected k-vector falls outside the projection associated with the other grain will be totally reflected if it strikes the grain boundary. The reflected electrons cannot participate in steady-state heat or electrical transport in polycrystals. Such effects should be large in hexagonal metals. In copper, using the tight binding expression, about 10 percent of the electrons at 5 ev are reflected at some boundaries if m^*/m is 1.55. The resultant resistance increase is not temperature dependent near 4°K as the author previously erroneously suggested.

* Research partially supported by the National Science Foundation.

D9. I. Comparison of the Measurements on the Two Hall Coefficients, R_0^* and R_1^*, with Predictions of a Simple Band Model. EMERSON M. PUGH AND F. E. ALLISON, *Carnegie Institute of Technology.*—Measurements of R_0^* now available on Co-Ni, Ni-Cu and Cu-Zn alloys appear to be in good agreement with predictions of a simple band model in those regions where this model can make unambiguous predictions. Good qualitative agreement exists throughout the series, which covers total electrons per atom from 27 to 30. Measurements on R_1^* appear to follow the Karplus-Luttinger law, $R_1 = A\rho^n$ (though $n \neq 2$) whenever ρ is changed by temperature alone. This law is sometimes followed when ρ is changed by alloying. However, the complete failure of the law when Co or Fe are added to Ni suggests the successes may be coincidental.

D10. Temperature Dependence of the Two Hall Coefficients in Three Cu-Ni Alloys. F. E. ALLISON AND EMERSON M. PUGH, *Carnegie Institute of Technology.*—The two Hall coefficients and the resistivity of Cu-Ni alloys containing 80%, 70% and 60% Ni have been measured from 4°K to 400°K. These alloys were chosen because early measurements had indicated that conduction in the 3 d-bands of these ferromagnetic alloys could be neglected. The values of R_0^*, from precise Hall measurements at high fields, are in excellent agreement with the predictions of the band model that divides the conduction band into parallel and antiparallel bands. The data on all three alloys fit the predicted curve at temperatures below their Curie points and also fit the predicted Curie point anomaly due to $\partial M/\partial B \neq 0$ at high fields in this temperature region. The dependence of R_1^* upon resistivity is in agreement with the law $R_1^* = A\rho^n$. For 80% and 70% Ni the coefficient A and the exponent n agree with the values obtained for pure Ni. A significant departure from the pure Ni value is observed, however, in the 60% Ni alloy. Evidence will be presented that indicates this law should be extrapolated through the temperature region above the Curie point where the alloys are paramagnetic.

THURSDAY MORNING AT 11:00

Stephen Foster Social Room

(G. C. WICK presiding)

DA1. Behavior of Slow Positrons in Solids. S. DE BENEDETTI, *Carnegie Institute of Technology.* (30 min.)

DA2. Experiments on Positron Annihilation. L. A. PAGE, *University of Pittsburgh.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Mellon Auditorium

(JOHN BARDEEN presiding)

Various Invited Papers of DSSP

E1. Role of the Uncertainty Principle in Conductivity Theory. H. W. LEWIS, *Bell Telephone Laboratories.* (30 min.)

E2. Theory of Spin Waves in Ferromagnets. F. J. DYSON, *Institute for Advanced Study.* (30 min.)

E3. Multiplet Structure of Excitons in Ionic Crystals. A. W. OVERHAUSER, *Cornell University.* (30 min.)

E4. Measurement of the Spin Susceptibilities of Metals. C. P. SLICHTER, *University of Illinois.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Mellon Institute Conference Room

(J. K. GALT presiding)

Phenomena of Magnetism

F1. Diamagnetism of Metallic Conduction Electrons.* T. KJELDAAS, *Westinghouse Research Laboratories,* AND W. KOHN, *Carnegie Institute of Technology.*—Recent measurements[1] of the spin susceptibility of Na and Li, when combined with measurements of the total susceptibility,[2] lead to diamagnetic susceptibilities much smaller than predicted by the Landau-Peierls formula. We have therefore reinvestigated the diamagnetic susceptibility of conduction electrons by the formalism of Luttinger and Kohn,[3] which employs a power series expansion in the wave vector **k**. The leading term is the usual Landau expression with the effective mass replacing the free electron mass. The next term has been explicitly evaluated. In contrast to the work of Peierls, the present calculation is not based on the tight binding approximation, but does correctly reduce to the atomic diamagnetism for the case of separated atoms. Numerical results for Li and Na will be presented.

* Supported in part by the Office of Naval Research.
[1] R. T. Schumacher and C. P. Slichter, Phys. Rev. **101**, 1 (1956).
[2] R. Bowers, Phys. Rev. **100**, 1141 (1955).
[3] J. M. Luttinger and W. Kohn, Phys. Rev. **97**, 869 (955).

F2. Magnetic Susceptibility of Some Synthetic Gems at Low Temperatures. J. G. DAUNT, J. W. SNIDER, AND K. BRUGGER, *Ohio State University.*—We have measured the temperature dependent susceptibility of synthetic ruby, blue spinel, aqua spinel, Burma sapphire, and green sapphire, which were supplied in the form of ½-in. diam spheres by the Linde Air Products Company, by an ac bridge method down to 1°K. The temperature dependent paramagentism of the ruby, which is Al_2O_3 with Cr impurity, could be described by: $\chi_T = 5.0\times10^{-4}/(T-0.20)$ emu/cm³. All other specimens cited showed $\chi_T = 0$. Adiabatic demagnetization of the ruby from initial fields up to 24 kilogauss have been carried out, yielding magnetic temperatures down to approximately 0.1°K. In view of the fact, as pointed out previously,[1,2] that synthetic ruby has many favorable qualities for demagnetization work, detailed results will be persented. Consideration also is given to its potential use as a substandard thermometer in the range 0.1° to 20°K.

[1] C. V. Heer and C. J. Rauch, Proc. Conf. Low Temp. Physics, Paris, 1955, Paper No. 25.
[2] J. G. Daunt and W. L. Pillinger, see reference 1, Paper No. 18.

F3. Anomalous Properties in Dilute Copper-Nickel Alloys. B. R. COLES,**Carnegie Institute of Technology* (introduced by P. A. Marcus).—A large number of physical properties of dilute copper-nickel alloys shows behavior inexplicable on a simple collective band picture.[1] In particular small additions of nickel to copper give a paramagnetic contribution to the susceptibility which, under some circumstances, increases with increase of temperature. A model is described which makes possible a semiquantitative interpretation of this behavior. This model requires isolated nickel atoms in a copper matrix to have their outer electrons in localized 3*d*-states, all of which are occupied at absolute zero, but from which electrons can be excited into the conduction band of the alloy. Anomalies in the electrical resistance of such alloys can be given a reasonable interpretation in terms of this model.

* On leave of absence from Imperial College, London, England.
[1] B. R. Coles, Proc. Phys. Soc. (London) **B65**, 221 (1952).

F4. de Haas-van Alphen Oscillations in the Thermal and Electrical Magnetoresistance of Tin. PERRY B. ALERS, *U. S. Naval Research Laboratory.*—A study has been made of the thermal and electrical magnetoresistance of tin at liquid helium temperatures in an attempt to find oscillatory behavior of the de Haas-van Alphen type. The tin specimen was a monocrystalline rod mounted transverse to the field direction and measurements were made with the tetragonal axis parallel to the magnetic field. The electrical measurements were made at about 1.7°K. After a preliminary survey of the magnetoresistive behavior, the region from 20 kilogauss to 25 kilogauss was closely investigated and oscillations were observed. Their amplitude was about 0.5 percent of the total resistance, and their frequency yielded a value for β^*/E_0 of 6.1×10^{-7} guass^{-1}. A similar procedure was employed in measurements of the thermal magnetoresistance. The temperature was about 3.1°K and oscillations were again detected above 20 kilogauss. The amplitude was less (about 0.2% of the total) and the value of β^*/E_0 derived from the frequency was 5.7×10^{-7} gauss^{-1}. Shoenberg,[1] in his work on the de Haas-van Alphen effect in the diamagnetic susceptibility of tin, gives a value of β^*/E_0 of 5.9×10^{-7} gauss^{-1}.

[1] D. Shoenberg, Trans. Roy. Soc. (London) **A245**, 1 (1952).

F5. Weak Temperature Dependence of "Van Vleck" Paramagnetic Susceptibility in Semiconductors. J. A. KRUMHANSL, *National Carbon Research Laboratories*, AND H. BROOKS, *Harvard University*.—Recent precision measurements[1] of the magnetic susceptibility of Ge, Si, and InSb allow one to separate from the total susceptibility the contribution of the lattice. Several features of the lattice susceptibility are: it is diamagentic; the magnitude is much smaller than expected; furthermore, there is a temperature dependence which was not expected. We believe this behavior can be explained on the basis of the (nominally) "temperature independent" paramagnetism discussed by Van Vleck in several applications. Particularly in the case of molecules this term often cancels an appreciable part of the diamagnetism. In the present case the weak temperature variation of susceptibility can be attributed to a change in the band-to-band excitation energy similar to the temperature change in energy gap. Semiquantitaive calculations have been carried out for the case of Ge, based on current models of the band structure. Group theoretical methods were used to determine selection rules for magnetic dipole transition between bands; K conserving transitions of minimum energy are not allowed so a direct identification of the temperature shifts with optical data is not possible.

[1] Stevens, Cleland, Crawford, and Schweinler, Phys. Rev. **100**, 1084 (1955).

F6. Magnetic Susceptibility of Silicon. D. K. STEVENS AND J. H. CRAWFORD, JR., *Oak Ridge National Laboratory*.—Reported here are recent measurements of the magnetic susceptibility of Si as a function of temperature. Both pure and impure specimens have been examined and the various contributions to the total susceptibility will be discussed. Particularly noteworthy is the behavior of the pure material which exhibits a decreasing diamagnetism with increasing temperature. At 300°C $d\chi/dT=3.0\times10^{-11}$ compared to a similar variation in Ge of $d\chi/dT=2.4\times10^{-11}$ cgs units. This behavior will be discussed in terms of the proposal of Krumhansl and Brooks[1] that this temperature dependence arises from the superimposed Van Vleck paramagnetism. Implications of this analysis for covalent binding in diamond lattice materials will be discussed.

[1] J. A. Krumhansl and H. Brooks (preceding abstract).

F7. Two-Band Model and Negative Magnetoresistance.* S. A. FRIEDBERG, *Carnegie Institute of Technology*.—Mott[1] has attributed the negative magnetoresistances found in ferromagnetic metals near their Curie points to a reduction with increasing magnetization of the number of empty d-states to which s-electrons with spins parallel to the magnetization may be scattered. A similar reduction in the $s-d$ scattering is also possible when a magnetic field is applied to a metal to which the two-band model applies but in which spontaneous magnetization does not occur. Should the Fermi surface in this material lie close to the top of the d-band an observable negative magnetoresistance is quite possible provided that the density of d-states at the Fermi level and its derivatives with respect to energy obey a simple condition. A general expression for the magnetoresistance due to this mechanism will be described. The possibility of observing negative magnetoresistances in certain alloys of transition metals will be considered as will the applicability of this picture to observed effects in semiconductors with impurity bands, e.g., InSb.

* Work supported in part by the Office of Naval Research and the National Science Foundation.
[1] N. F. Mott, Proc. Roy. Soc. (London) **A153**, 699 (1936).

F8. Low Field Magnetoresistance Calculations for Holes in Germanium and Silicon.* J. G. MAVROIDES AND B. LAX, *Lincoln Laboratory*.—Magnetoresistance is highly dependent on the scattering, more so than either the zero-field Hall constant or electrical conductivity and as such serves as a useful tool for examining the scattering processes. We have used a series expansion method which has been previously described[1] to evaluate the magnetoconductivity coefficients for warped energy surfaces at low magnetic fields. Using experiment values of Hall constant and conductivity, and assuming a relaxation time of the form $\tau=l\epsilon^{-\lambda}$, where l is a temperature dependent coefficient, ϵ is the energy of the carriers, and λ is a parameter which most suitably represents the scattering processes, we have calculated the magnetoresistance coefficients. The results of these calculations are used to interpret the experimentally derived directional magnetoresistance effects in p-type germanium[2] and silicon.[3]

* The research reported in this document was supported jointly by the U. S. Army, Navy, and Air Force under contract with Massachusetts Institute of Technology.
[1] J. G. Mavroides and B. Lax, Phys. Rev. **99**, 1656 (A) (1955).
[2] G. L. Pearson and H. Suhl, Phys. Rev. **83**, 768 (1951).
[3] G. L. Pearson and C. Herring, Physica **20**, No. 11, 975 (1954).

F9. Magnetic Field Dependence of the Hall Coefficient in p-Type Germanium at 77°K. E. L. PETERSON, J. A. SWANSON, AND G. L. TUCKER, *IBM Research Laboratory*.—The Hall coefficient has been measured as a function of magnetic field strength for several high purity p-type germanium single crystals at 77°K. A minimum has been found at about 2000 gauss. The Hall coefficient saturates at high fields.[1] The ratio of $R_{\min}$ to R_{satn} is 0.94. The minimum may be explained by the assumption that μ_H/μ_D is less than unity for heavy holes. This assumption is consistent with the warping of the surfaces of constant energy for holes resulting from spin-orbit interaction,[2] together with the fact pointed out by Shockley that sufficiently warped energy surfaces can give values of μ_H/μ_D less than unity.[3]

[1] Harman, Willardson, and Beer, Phys. Rev. **94**, 1065 (1954). J. A. Swanson, Phys. Rev. **99**, 1799 (1955).
[2] Dresselhaus, Kip, and Kittel, Phys. Rev. **95**, 568 (1954).
[3] W. Shockley, *Electrons and Holes in Semiconductors* (D. Van Nostrand Company, Inc., New York, 1950), p. 339.

F10. Thermomagnetic Effects in Germanium. C. HERRING AND T. H. GEBALLE, *Bell Telephone Laboratories*.—The Nernst field $E_N=-BH\times\Delta T$ and the magneto-Seebeck effect have been measured for moderately high purity germanium. Theoretically $B=B_e$(electronic)$+B_p$(phonon drag).[1] For n-germanium, B is dominated by $B_e<0$ above 175°K and by $B_p>0$ below. With $B_p=\gamma Q_p\mu_H/c$ (Q_p=phonon part of thermoelectric power, μ_H=Hall mobility) observed γ's were 0.25 to 0.3 above 30°K and 0.4 at 10°K. These values are theoretically related to both the mass anisotropy and to the anisotropy of the phonon-electron interaction, on which they can provide valuable information. As expected B decreases markedly when $\mu_H H/c\gtrsim$one radian and becomes quite orientation-dependent. At low H the sign of B_p for p-germanium is opposite to that for n-type. Increasing H reverses the sign and ultimately decreases B_p again. The sign reversal is associated with the two-band model and the magnitude of B_p again depends on anisotropy of the lattice scattering. As expected, the increase of Q_p with H is of the same order as the increase of resistivity.

[1] P. J. Price, Bull. Am. Phys. Soc. Ser. II, **1**, 47 (1956).

F11. Anisotropy in Cyclotron Absorption in Bismuth.* S. FONER, H. J. ZEIGER, R. L. POWELL, W. M. WALSH, JR.,† AND BENJAMIN LAX, *Lincoln Laboratory*.—Microwave measurements in Bi at 23 000 Mc sec have been extended[1] to study the anisotropy of cyclotron absorption. Traces of the derivative of power absorption with respect to dc magnetic field H have been obtained as a function of H. A trigonal surface of the crystal was made part of the wall of a cylindrical cavity operated in a TE_{011} mode with linear polarization. Traces were obtained with H perpendicular to the surface, and as a function of orientation of H in the plane of the surface. Anisotropy

effects with 60° symmetry were observed for H in the trigonal plane. Although the effective mass values deduced from the data using classical electromagnetic theory[1] are in the same range as values for Bi obtained in other experiments,[2] a detailed explanation of the observed data has not as yet been found. Experimental results and a review of the status of current theories will be discussed.

* The research reported in this document was supported jointly by the U. S. Army, Navy, and Air Force, under contract with Massachusetts Institute of Technology.
† Now at Harvard University.
[1] R. N. Dexter and B. Lax, Phys. Rev. **100**, 1216 (1955).
[2] D. Schoenberg, Trans. Roy. Soc. (London) **A425**, 11 (1952).

F12. Evaluation of Some Nonlocal Theoreis for a Thin Superconducting Film.* J. R. SCHRIEFFER, *University of Illinois.*—The magnetization of a thin superconducting film has been evaluated as a function of film thickness on the basis of nonlocal theories proposed by Pippard,[1] Bardeen,[2] and Schafroth and Blatt.[3] Two limiting boundary conditions corresponding to specular reflection and random scattering of the electrons at the surface have been applied. The former boundary condition admits a Fourier solution in the form of a rapidly convergent series while a variational calculation was carried out for the latter condition. Deviations from the London theory occur for a thickness less than twice the penetration depth and give a magnetization smaller than the London value. Largest deviation is found for the Pippard theory with specular reflection and least for the Schafroth-Blatt version. These calculations will be compared with Lock's experimental results on thin tin films.[4]

* Supported by the Office of Ordnance Research, U. S. Army.
[1] A. B. Pippard, Proc. Roy. Soc. (London) **A216**, 517 (1953).
[2] J. Bardeen, Phys. Rev. **97**, 1724 (1955).
[3] M. R. Schafroth and J. M. Blatt, Phys. Rev. **100**, 1221 (1955).
[4] J. M. Lock, Proc. Roy. Soc. (London) **A208**, 391 (1951).

THURSDAY AFTERNOON AT 2:00

Mellon Institute Social Room

(J. G. FOX presiding)

Invited Papers in Nuclear Physics

G1. Pion Production in Nucleon-Nucleon Collisions. T. H. FIELDS, *Carnegie Institute of Technology.* (30 min.)

G2. Scattering Experiments with 350-Mev Polarized Neutrons. R. T. SIEGEL, *Carnegie Institute of Technology.* (30 min.)

G3. Neutron-Proton and Proton-Proton Scattering at High Energies. LINCOLN WOLFENSTEIN, *University of Pittsburgh.* (30 min.)

Post-Deadline Papers, If Any

THURSDAY AFTERNOON AT 2:00

8 Cathedral of Learning

(W. KOHN presiding)

Carbon and Other Semiconductors

GA1. Electric Resistivity of Carbon Powders under Pressure.* S. MROZOWSKI, *University of Buffalo.*—The resistivity ρ of coke powder was investigated at room temperature as a function of applied pressure P, particle size, temperature of heat treatment, and surface conditions. On a log-log plot ρ *vs* P yields a straight line with a slope s between -0.55 and -0.6. The resistance is due to the spreading resistances near the contacts; since the contact areas are proportional to the yield stress for the material a proportionality of ρ with $P^{-\frac{1}{2}}$ is expected. A slightly steeper slope is obtained due to variation in number of contents per particle with the density of packing. Differences in packing result also in small differences of resistivity for powders with different particle sizes. Films of insulating fluids covering the particles are pushed out from the contacts and do not affect the resistivity. This is not so for films attached by valence forces. When coke is ground in air the freshly formed surfaces are oxidized and both ρ and s become higher. For very fine powders, slopes up to -0.8 were obtained. Removal of the oxide layers by heat treatment to 900°C restores the lower resistivity and brings down the slope to its normal value.

* Performed in part under the auspices of the U. S. Atomic Energy Commission.

GA2. Electric Resistivity of Heat-Treated Carbon Blacks.* H. T. PINNICK† AND S. MROZOWSKI, *University of Buffalo.*—For most of the untreated carbon black powders the room temperature resistivity *versus* pressure curves are not exactly straight on the log-log plot, but can be decomposed roughly into a sum of two components, one with a slope $s\sim-\frac{1}{2}$ (or less, see the following) due to spreading resistances and the other with a slope $s\sim-1$, due to the resistance of surface films. Removal of the surface films by heat treatment (H.T.) to above 900°C results in a general decrease of the resistances from both sources and in a decrease of the slope to the pure spreading-type value. A further decrease of the resistance is observed up to H.T.$\sim$1400°C, above which the resistance begins to increase and continues to do so up to a maximum which is reached for coarser carbon blacks around 2200°C, but

is not reached for the very fine ones even at H.T. 3000°C. The resistivities for H.T. >1000°C depend mainly on the particle size, the order being roughly the same for all H.T. For the finest carbon blacks, $|s| < \frac{1}{3}$, thus showing that elastic deformations prevail at the interparticle contacts.

* Supported in part by the Office of Naval Research.
† Now at Metals Research Laboratories, Electro Metallurgical Company, Niagara Falls, New York.

GA3. Hall, Thermoelectric and Magnetoresistive Effects in Heat-Treated Carbon Blacks.* A. CHABERSKI, E. E. LOEBNER,† AND S. MROZOWSKI, *University of Buffalo.*—In order to clarify the cause of the increase of resistance of carbon blacks for heat treatments (H.T.) above 1400°C, the thermoelectric power θ was investigated at room temperature as a function of H.T. While for cokes, after an increase between 1200°C up to H.T. ~2050°C, a fast decrease of θ is observed at higher H.T., the thermopower for carbon blacks continues to increase towards a maximum, which is reached for coarser carbon blacks around 2700°C, but is not reached for the very fine ones even for H.T. ~3000°C. Evidently the increase in resistance is mainly due to a decrease in number of positive carriers without the concurrent appearance of negative carriers excited into the upper band (as it occurs for cokes and other carbons). Solid pieces made without binder from one of the carbon blacks (*P33*) were investigated at room and liquid nitrogen temperatures. The Hall constant shows a variation with H.T. roughly similar to θ. All through the range 2000°C < H.T. < 3000°C a large negative magnetoresistance is observed, reaching almost 1% for 13 000 oersteds at 78°K (for H.T. ~2500°C).

* Supported in part by the Office of Naval Research.
† Now at RCA Research Laboratories, Princeton, New Jersey.

GA4. A High-Temperature Boron Graphite-Graphite Thermocouple. R. L. SHEPARD, H. S. PATTIN, AND R. D. WESTBROOK, *National Carbon Research Laboratories.*—A study of the effect of small amounts of boron on the electrical properties of graphite has shown that about one percent of boron changes the thermoelectric power of graphite from −5 μv/°C. for pure graphite to +15 μv/°C. for the boronated graphite with respect to copper at room temperature. A couple comprised of a pure graphite rod and a boronated graphite rod has produced over 100 mv at 3000°C. The thermocouple is sensitive to temperature differences of less than 10°C and stable up to at least 2600°C in neutral or reducing atmospheres such as are found in industrial furnaces or vacuum furnaces. The low electrical resistivity, high thermal conductivity, and excellent machinability of plain and boronated graphite allow convenient instrumentation, fast response, and easy construction of the couples.

GA5. Quenched-In Lattice Defects in Graphite.* MANUEL A. KANTER AND GERHART R. HENNIG, *Argonne National Laboratory.*—Marked changes in electrical properties of artificial graphite upon quenching from approximately 2000°C have been reported by Kinchin.[1] To determine whether his observed effects were due to lattice defects or impurities, quenching experiments were performed using small well-formed crystals of highly purified natural graphite under conditions where contamination was carefully avoided. Crystals were quenched from 3000°C to room temperature at a cooling rate of approximately 1400°C in the first 0.1 sec. Quenching under these conditions produced no measurable change in the room temperature magnetoresistance, the property deemed most sensitive to the presence of lattice defects which could be conveniently measured using very small crystals. The magnetoresistance of similar crystals containing lattice defects produced by irradiation with fast neutrons was measured to determine the sensitivity of the method. A minimum value of 3 ev for the heat of formation of lattice defects in graphite can be estimated using these measurements and the previously reported self-diffusion constant for graphite.[2]

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. H. Kinchin, Proc. Roy. Soc. (London) **A217**, 9 (1953).
[2] M. A. Kanter, Phys. Rev. **98**, 1563 (1955).

GA6. Bitter Magnets in Graphite Single Crystals.* N. N. AXELROD AND D. L. DEXTER, *University of Rochester.*—In graphite single crystals the resistivity in the *c*-direction (perpendicular to the layer planes), ρ_c has been reported several orders of magnitude greater than that in the *a*-direction. Screw dislocations parallel to the *c*-axis, as evidenced by spiral growth in natural crystals,[1] would thus furnish a low-resistivity path in the *c*-direction, through the spiral "staircase" nature of the layer planes around the screw axis. The net effect on ρ_c would be small unless a high dislocation density should exist, perhaps 10^{10} cm^{-2}. Around each screw axis, however, the current flow would be helical, producing a magnetic field. The results of the calculation of the field will be presented. The cancellation of field to be expected from the presence of both positive and negative screw dislocations makes improbable the simple observation of the field by macroscopic techniques, but powder techniques may be feasible.

* Research supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] F. H. Horn, Nature **170**, 581 (1952).

GA7. Calculation of the Effect of a Magnetic Field on the Conduction Electrons of Graphite. J. W. MCCLURE, *University of Oregon.*—The conduction electrons of graphite are situated near the edges of the Brillouin zone, where several bands are degenerate. The usual effective mass theory cannot be applied to such electrons. We have calculated the energy spectrum of these electrons in the presence of a magnetic field, treating the motion of the electrons by the method of Luttinger and Kohn, and using the two-dimensional energy band calculation by Wallace. We find that all the energy levels induced by the magnetic field have the same degeneracy (which is proportional to the field strength). The energy of a level in the high quantum number limit is proportional to the square root of the product of an integer times the field strength. The periodicity of the de Haas-van Alphen effect is preserved. It seems likely that the large diamagnetic susceptibility of graphite may be explained by these considerations, in agreement with the ideas of Adams.

GA8. Atomic Heat of Diamond Between 10° and 200°K.* D. L. BURK AND S. A. FRIEDBERG, *Carnegie Institute of Technology.*—The atomic heat of diamond has been measured between 10° and 200°K. The specimen consisted of 8.3 moles of clear chips.[1] Measurements were carried out by a vacuum calorimetric method using a thin-walled open aluminum capsule designed to provide a more favorable ratio of the heat capacities of specimen and capsule than has heretofore been possible at the lowest temperatures. The results will be discussed in terms of a curve of effective θ_D *vs* T. Above 75°K our values are in agreement with previous results.[2] At lower temperatures the new θ_D values seem to be significantly different. At 22°K $\theta_D = 2180° \pm 80°$K.

* Work supported in part by the Office of Naval Research and the National Science Foundation.
[1] Obtained through Professor R. Smoluchowski from C. J. Koebel, Koebel Diamond Tool Company.
[2] W. De Sorbo, J. Chem. Phys. **21**, 876 (1953).

GA9. Low-Temperature Electrical Conductivity of Germanium. S. H. KOENIG AND G. R. GUNTHER-MOHR, *IBM Watson Laboratory.*—Measurements on *n*-type germanium previously described[1] have been improved and extended in temperature range. From the I-V characteristic alone in the

prebreakdown, nonlinear, region, conduction band and impurity band current contributions can be separated. Confirming the expectation that the impurity band acts as a passive, ohmic resistance in parallel with the conduction band. The current density *vs* electric field fits the following expression within experimental accuracy ($\frac{1}{2}\%$) over one decade of linear current and four or more decades of nonlinear prebreakdown currents: $j=\sigma_0 E+\sigma_1 E^{n_1}+\sigma_2 E^{n_2}$. The temperature dependence of the nonlinear part shows a single activation energy law wihich does not saturate as temperature is reduced to where impurity band conduction is dominant in the linear range. In the region where σ_0 is dominant, the Hall angle is independent of E. In the "σ_1" region, the Hall angle increases less than a factor of 2 and then falls off at breakdown.

[1] S. H. Koenig and G. R. Gunther-Mohr, Phys. Rev. **98**, 228 (1955).

GA10. Neutral Impurity Scattering in Semiconductors. N. SCLAR, *Naval Research Laboratory.*—Many neutral atoms have a tendency to acquire an electron and become negative ions. These neutral atoms must therefore have a short range attractive influence on free electrons which will give rise to an additional mechanism for scattering of the electrons.[1] The scattering from neutral impurities in semiconductors by this mechanism has been calculated using the partial wave treatment developed for scattering by ionized impurities.[2] Of interest is the case of resonance scattering when $\bar{\epsilon}\sim|\epsilon_N|\sim kT$ where $\bar{\epsilon}$ is the average energy of the charge carriers and ϵ_N is the additional energy level associated with the neutral impurity. This case yields $\mu=(2qm^{*\frac{1}{2}}/\sqrt{2}\pi^{\frac{1}{2}})(|\epsilon_N|^{\frac{1}{2}}/N_N\hbar^2)$. When we use for $|\epsilon_N|$ the value appropriate for hydrogen reduced by the dielectric constant of the medium, we get a result applicable in germanium to $T\sim 6°$K, which gives $\mu_{exp}/\beta^{\frac{1}{2}}$ where β is the effective electronic mass to free mass ratio and μ_{exp} is the mobility calculated by Erginsoy[3] for neutral impurity scattering from an entirely different approach.

[1] A. I. Ansel'm, J. Exptl. Theoret. Phys. U.S.S.R. **24**, No. 1, 85 (1953).
[2] N. Sclar, Bull. Am. Phys. Soc., Ser. II, I, No. 1, 48 (1956).
[3] C. Erginsoy, Phys. Rev. **79**, 1013 (1950).

GA11. Combination of Scattering by Optical Modes and by Acoustical Modes in a Classical Semiconductor.* V. A. JOHNSON, *Purdue University.*—If conduction electrons are subject to two simultaneous scattering processes characterized by different energy dependences of their respective mean free paths, the resulting resistivity is greater than the sum of the resistivities arising from the two processes separately. The combination of the two scattering processes must also be considered in the evaluation of the Hall coefficient and thermoelectric power. This problem has been previously treated for the combination of scattering by acoustical lattice vibrations and by impurity ions in a classical semiconductor, e.g., by Johnson and Lark-Horovitz.[1] Experimental evidence shows that both the optical modes and the acoustical modes are effective in producing lattice scattering in lead compounds, III-V compounds, and other semiconductors. Computations have now been made, for a classical semiconductor, of the effects produced by combining scattering by the acoustical modes (l independent of temperature) and by optical modes (l proportional to carrier kinetic energy). It is found that the combined resistivity may be up to 11% greater than the sum of the two separate components, the numerical factor in the Hall coefficient ranges between 1.18 and 1.01, and the mean-free-path term in the thermoelectric power varies between $2k/e$ and $3k/e$.

* Work assisted by U. S. Signal Corps Contract.
[1] V. A. Johnson and K. Lark-Horovitz, Phys. Rev. **82**, 977 (1951).

GA12. Impurity Band Conduction in Mercury-Doped Vacuum.* P. H. MILLER, JR., *University of Pennsylvania*, AND J. H. TAYLOR, *Morgan State University.*—In a certain sense the first person to observe impurity band conduction was F. Birch[1] who investigated the electrical conduction of mercury vapor near the critical point. The lowest density at which he reports observations gives a conductivity of approximately 5×10^{-3} ohm^{-1} cm^{-1} at 1640 atmos and 1500°C where the density is approximately 9×10^{21} cm^{-3}. Using Hartree wave functions we estimate that impurity band conduction should become important at a density of the order of 3×10^{21} cm^{-3}. In some preliminary experiments we find that the conductivity of vapor in equilibrium with the liquid begins to increase rapidly at 1000°C and reaches a value of 10^{-4} ohm^{-1} cm^{-1} at 1050°C and 300 atmos where the density is approximately 2×10^{21} cm^{3}.

* Supported in part by the Office of Naval Research.
[1] F. Birch, Phys. Rev. **41**, 641 (1932).

GA13. Anomalous Reflection from Rutile.* J. R. JOHNSON AND P. H. MILLER, JR., *University of Pennsylvania.*—Work previously reported[1] has been extended to obtain an expression for the reflection coefficient for the surface of an anisotropic absorbing substance in terms of the refractive indices and absorption constants. Measurements have been made on an optically flat surface of an oriented transparent rutile crystal using visible light. At 4100 A the indices were found to be 2.809, 2.765, i.e., about 10% less than the published values. The absorption constants so obtained were so large that the crystal should have been opaque. Calculations show that the presence of a dielectric layer on a dielectric base can produce a type of reflection coefficient which the simple theory[1] would interpret as being due to absorption. It seems to be possible to account for such a layer on the basis of the fact that the traditional "local field" calculations are no longer valid near the surface, particularly in materials of high index of refraction.

* Supported in part by the Office of Naval Research.
[1] P. H. Miller, Jr., and J. R. Johnson, Physica **20**, 1024 (1954).

THURSDAY AFTERNOON AT 2:00

132 Cathedral of Learning

(R. L. ANTHONY presiding)

Second Session of DHPP

Invited Paper

H1. The Dynamic Properties of Various Rubbers at High Frequencies. D. G. IVEY, *University of Toronto.* (30 min.)

Business Meeting of the Division of High-Polymer Physics

Contributed Papers

H2. Ladder Structures for Representation of Viscoelastic System. B. Gross, *Instituto Nacional de Tecnologia, Rio de Janeiro.*—Blizard[1] has introduced a model constituted of identical springs and dashpots arranged in the form of a ladder network. With the aid of this working model we have calculated the characteristic functions of linear viscoelasticity. Closed expressions for complex modulus and compliance function and series expressions (with a finite number of terms) for relaxation and creep function are obtained. It can be shown that the compliance function is identical with that of Bueche,[2] and modulus and relaxation functions identical with those of Rouse.[3] Since in linear viscoelasticity identity of two functions belonging to different theories means identity of all others, the results prove the formal *identity* of the theories of Blizard, Bueche, and Rouse. The full extent of these theories has now been calculated. The convenience of the model treatment is also shown by the fact that it gives modulus and compliance in closed form. Formal model considerations show also the validity of Ferry's[4] temperature reduction.

[1] R. B. Blizard, J. Appl. Phys. **22**, 730 (1951).
[2] F. Bueche, J. Chem. Phys. **22**, 603 (1954).
[3] P. E. Rouse, Jr., J. Chem. Phys. **21**, 1272 (1953).
[4] J. Ferry, J. Am. Chem. Soc. **72**, 3746 (1950).

H3. Dynamic Mechanical Properties of Poly-*n*-butyl Methacrylate.* William C. Child, Jr., and John D. Ferry, *University of Wisconsin.*—Values of complex shear compliance $(J'-iJ'')$ have been obtained for a fraction of poly-*n*-butyl methacrylate of weight-average molecular weight 3.05×10^6, prepared by Picatinny Arsenal, at 18 temperatures from 44° to 130°C and at frequencies between 24 and 2400 cps, with the Fitzgerald transducer apparatus. The range of J' was from 4.8×10^{-7} to 2.6×10^{-10} cm²/dyne, covering the transition from rubber-like to glass-like consistency. When reduced to 100° by the method of reduced variables, all data superpose to form single composite curves for J' and J'', except for a small anomaly near the maximum of J'': the height of the maximum increases slightly with increasing temperature. The temperature shift factor a_T follows the equation of Williams, Landel, and Ferry with a modification of the constants corresponding to an unusually small apparent thermal expansion of the free volume. The relaxation and retardation distribution functions are rather similar in shape to those of polyisobutylene but less steep than those of polymethyl acrylate. By comparison with the Rouse theory, the friction coefficient per monomer unit is calculated to be 3.5×10^{-4} dyne-cm/sec at 100°.

* Supported by the Ordnance Corps, Department of the Army.

H4. Dynamic Mechanical Properties of Polyethyl Methacrylate.* John D. Ferry, William C. Child, Jr., Robert Zand, and Donald M. Stern, *University of Wisconsin.*—Values of complex shear compliance $(J'-iJ'')$ have been obtained for two fractions of polyethyl methacrylate, prepared by Picatinny Arsenal, of weight-average molecular weights 0.164 and 1.73×10^6. Measurements were made with the Fitzgerald transducer apparatus at 17 temperatures from 75° to 155°C and at frequencies between 24 and 2400 cps. The results for the two fractions were practically identical; J' ranged from 1.98×10^{-7} to 1.6×10^{-10} cm²/dyne. The J'' data could be reduced to a single composite curve at 100° by shift factors a_T which followed the equation of Williams, Landel, and Ferry with a slight modification of the constants. The J'-data could be reduced in this manner only between 140° and 155°C. At lower temperatures, J' was progressively larger than would be expected from a shift in time scale alone. Nevertheless, the same retardation distribution function was obtained from both J' and J''. The anomaly can be qualitatively interpreted by a secondary loss mechanism which shifts less rapidly with temperature than the primary mechanism. The relaxation and retardation spectra are similar in shape to those of poly-*n*-butyl methacrylate. By comparison with the Rouse theory, the friction coefficient per monomer unit is calculated to be 0.85 dyne-cm/sec at 100°.

* Supported by the Ordnance Corps, Department of the Army.

H5. The Viscoelastic Properties of Poly(Methyl Acrylate). J. B. Kinsinger and J. A. Schreiber, *Rohm & Haas Company* (introduced by T. G. Fox).—Tensile creep data were obtained for poly(methyl acrylate) of weight-average molecular weight 5×10^6. Compliance *versus* log time curves, in the temperature range 8 to 37°C, were superposed to obtain an experimental creep curve extending over six decades of time. A creep curve calculated by the recent theory of viscoelasticity of Bueche[1] was in reasonable agreement with the experimental result. Certain deviations were noted, however, and possible sources of these will be discussed. The temperature dependence of the creep curve was in agreement with results obtained by dynamic measurements of Williams and Ferry[2] and can be adequately represented by the recent empirical relationship of Williams, Landel, and Ferry which relates the temperature coefficient to the glass temperature of the polymer.

[1] F. Bueche, J. Appl. Phys. **26**, 6 738 (1955).
[2] Williams and Ferry, J. Colloid Sci. **10**, 5, 474 (1955).
[3] Williams, Landel, and Ferry, J. Am. Chem. Soc. **77**, 3701 (1955).

H6. Viscoelastic Theory of Branched and Cross-Linked Polymers. Joe S. Ham, *E. I. du Pont de Nemours and Company.*—A model of polymer chain motions is developed that can be readily applied to branch chained and cross-linked systems. This model is similar to the one proposed by Rouse[1] in a theory of viscoelasticity which satisfactorily explains many of the properties of straight-chain polymers in solution and in bulk. In both cases, the motion of polymer chains is assumed to arise from the external forces and the forces derived from a chemical potential. This chemical potential is calculated from statistical mechanical arguments. The mathematics of the new model is similar to that required in the free electron method of calculating electronic structure, whereas the mathematics in the method of Rouse is analogous to the molecular orbital approximation. Both methods give essentially the same distribution of relaxation times in the region of applicability for linear polymers in solution. The new method has simple boundary conditions permitting easy extension to branched systems. The distribution of relaxation times is calculated for variously shaped polymer molecules and for various models of a cross-linked material. These results are compared with experimentally determined distributions.

[1] P. E. Rouse, J. Chem. Phys. **21**, 1272 (1953).

H7. Some Thermodynamic Properties of Cellulose Nitrate Networks. Paul Drechsel, Seymour Newman, and Samuel Kardon, *Allegany Ballistic Laboratory.**—The equilibrium elastic and swelling properties of highly plasticized, cross-linked, cellulose nitrate have been examined. A thermodynamic analysis of deformation as a function of temperature shows that the assumption of negligible internal energy valid for the elasticity of rubber is not applicable in this case. Over a wide range of cross linking, profound disagreement is noted between the cross-linking levels determined directly by chemical analyses and computed from swelling data using the equilibrium swelling expression derived from the statistical theory of rubber elasticity. At low levels of cross linking closer agreement is observed between cross-linking levels calculated from the elastic modulus and from swelling data. Our results are consistent with the concept of a network of

stiff cellulose nitrate chains highly extended in the unstrained state.

* The Allegany Ballistics Laboratory is a facility owned by the U. S. Navy and operated by the Hercules Powder Company.

H8. Ultrasonic Propagation Properties of Saturated Hydrocarbons.* J. M. YOUNG† AND A. A. PETRAUSKAS, *University of Notre Dame.*—Ultrasonic propagation properties of 2-methylbutane, 3-methylpentane, *n*-pentane, 2,3-*di*-methylbutane, and 2,2-*di*-methylbutane were studied using a pulse method in the range from 1 mc to 35 mc and from 130°K to 280°K. These studies revealed the existence of an attenuation peak in 2-methylbutane, in 2,3-*di*-methylbutane, and in 3-methylpentane. These peaks were found to be consistent with a single relaxation process. Activation energies for the relaxation process in 2-methylbutane and 3-methylpentane were found to be about 4.7 kcal/mole, and about 3.3 kcal/mole in 2,3-*di*-methylbutane. No absorption was observed in *n*-pentane and 2,2-*di*-methylbutane. In a mixture of 3-methylpentane and *n*-pentane, measurements at 5 mc showed an absorption peak at the same temperature as in 3-methylpentane, reduced in amplitude in proportion to the reduction in the number of molecules of 3-methylpentane. The ultrasonic velocity decreased from about 2000 m/sec at 120°K to about 1000 m/sec at room temperature. No dispersion in velocity could be detected within the experimental accuracy. A gradual change in the slope of the velocity *versus* temperature curve was observed in this temperature range. These observations indicate that the mechanism of absorption is explainable in terms of a hindered rotation (about the middle C−C bond in butanes and about the 2nd and 3rd C−C bonds in 3-methylpentane).

* Supported in part by the Office of Naval Research.
† Now at DuPont Laboratories.

FRIDAY MORNING AT 9:30

132 Cathedral of Learning

(A. W. NOLLE presiding)

Third Session of DHPP

J1. Birefringence Changes During Retraction of Oriented Polystyrene Monofilaments. I. Changes of Average Birefringence. R. D. ANDREWS AND J. F. RUDD, *The Dow Chemical Company.*—The birefringence changes during retraction have been measured at 85°C for four different oriented polystyrene monofilaments with different initial birefringence. When the data are plotted as percent of original birefringence *vs* percent of original length, it is evident that the relationship is not linear, and also that the curves are different for the four filaments. Birefringence decays more rapidly than the length decreases, in all cases. The birefringence-length curve is also relatively insensitive to temperature. Various possible relationships between birefringence and length were tested: birefringence was plotted as percent of original birefringence, and in absolute units; length was plotted as percent of original length, percent of final length, and percent of total length change. In no case was a relationship obtained which was the same for all the filaments, indicating that birefringence is not a simple function of length or extension. The possibility that birefringence decay could be interpreted in terms of the distribution of retardation times characteristic of the material (assuming that the birefringence decay and length decrease are proportional by a constant ratio for each retardation time) was also checked, and was found not to hold for the four filaments investigated.

J2. Birefringence Changes During Retraction of Oriented Polystyrene Monofilaments II. Changes in Radial Distribution of Birefringence. J. F. RUDD AND R. D. ANDREWS, *The Dow Chemical Company.*—In connection with the measurements of changes in average birefringence of oriented polystyrene monofilaments during retraction, it seemed desirable to study these birefringence changes in more detail by investigating the changes in the complete radial distribution of birefringence at a single temperature (85°C) for one of the filaments used in Part I. The filament chosen for this purpose was the one which showed the greatest variation in local birefringence across its diameter. The radial distribution was measured at different stages of the retraction process by cutting wedges on the end of the sample and analyzing the interference pattern obtained by observation of the wedge under a polarizing microscope. By plotting curves of percent of original birefringence *vs* log time for different radius values, it is evident that the birefringence decay function is different at different points along the radius. The birefringence is initially negative throughout, but as retraction approaches completeness, the birefringence values in the center of the filament become slightly positive in sign, indicating that the molecules in this region are assuming a lateral orientation. This effect takes place to such a degree that the over-all retardation through the diameter, and consequently the average birefringence, becomes positive also.

J3. Investigation of the Flow Birefringence and Viscosity of Concentrated Solutions. W. PHILIPPOFF, *Franklin Institute.*—According to present theory, the phenomena of non-Newtonian viscosity and flow birefringence are closely connected, both being determined by the orientation of particles in laminar flow. The theory for infinite dilution has been already treated extensively. However, in the case of more concentrated solutions, only one suggestion of Peterlin exists. To obtain further information, we have used large ranges of variables in the investigation of the flow birefringence of a 15% solution of polyisobutylene in decalin. This solution has been extensively investigated, both with respect to its flow and dynamic behavior. The measurements of the flow birefringence were performed at 30 and 50°C in a range of rates of shear from 0.007 to 4.57 sec^{-1}. Both the degree of birefringence, Δn, and the orientation angle, χ, when plotted over the rate of shear conform closely to the theoretical shape developed for rigid particles orientated in flow. However, when these two quantities were plotted over shearing stress, both temperatures gave one identical curve in the whole range, the curve approached the expectancy for deformable particles. The calculated rotational diffusion constant from the birefringence was completely different from the relaxation time determined from the dynamic tests. These preliminary tests suggest that the further application of the same mode of investigation could lead to valuable information concerning the flow behavior of polymer solutions.

J4. Effect of Light Scattering upon the Apparent Refractive Index of Dispersed Polymers.* M. NAKAGAKI AND W. HELLER, *Wayne University.*—Precise determinations of particle size and molecular weight of polymer spheres by means of the Mie theory requires that the refractive index of the light scattering material is accurately known. An experimental determination of the refractive index, using any of the existing mixture rules proved inadequate unless the results obtained are extrapolated to zero-particle size.[1] At all finite particle sizes, the refractive index obtained is only an apparent quantity due to complications arising from both forward and backward scattering. Following recent work by Zimm and Dandliker,[2] concerned with the effect of forward scattering upon the Rayleigh ratio, the theoretical variation of the apparent refractive index was established as a function of the theoretical forward scattering as derived from the Mie theory. The computations were carried out for a series of relative refractive indices up to 1.30 and for α values up to 8.0, covering herewith the entire submicroscopic range. The theoretical data obtained fit very satisfactorily the experimental data referred to above.

* This work was supported by the Office of Naval Research.

[1] W. Heller and T. L. Pugh, paper presented before the Division of Polymer Chemistry at the 128th meeting of the American Chemical Society, Minneapolis, Minnesota, September, 1955.

[2] B. H. Zimm and W. B. Dandliker, J. Phys. Chem. **58**, 644 (1954).

J5. Influence of Diluent and of Copolymer Composition on the Glass Temperature of a Polymer System. T. G. FOX, *Rohm & Haas Company.*—A relationship for the dependence of the glass temperature on composition for a copolymer or a plasticized polymer may be derived from simple assumptions. In the limiting form it becomes

$$\frac{1}{T_g}=\frac{w_1}{T_g(1)}+\frac{w_2}{T_g(2)}.$$

For a plasticized polymer $T_g(1)$ and $T_g(2)$ represent the glass temperatures of the pure polymer and pure diluent, and w_1 and w_2 are their respective weight fractions in the mixture. For a copolymer, w_1 and w_2 refer to the weight fraction of the two comonomers, whereas $T_g(1)$ and $T_g(2)$ refer to the glass temperatures of the two corresponding homopolymers. This equation may be expected to apply to systems which are compatible and not too strongly polar. Data on copolymers and on polymer-diluent systems illustrate that this is substantially true.

J6. Glass Temperatures of Poly-(Chlorotrifluoroethylene), Poly-(Vinylidene Fluoride), and their Copolymers.* L. MANDELKERN, G. M. MARTIN, AND F. A. QUINN, JR., *National Bureau of Standards.*—The glass temperatures of poly-(chlorotrifluoroethylene), poly-(vinylidene fluoride), and five of their copolymers of varying composition were determined using volume dilatometers and an automatic recording interferometer. The glass temperatures for the two homopolymers were found to be in the range +30° to 35°C for poly-(chlorotrifluoroethylene) and −25° to −30°C for poly-(vinylidene fluoride). A quenched sheet of poly-(chlorotrifluoroethylene) originally formed by compression molding displayed a 1% increase in thickness on initial heating above 30°C but this phenomenon did not manifest itself on subsequent cooling and heating cycles. The glass temperatures Tg, of the copolymers ranged between the values of the two homopolymers. However, in order for the simple linear relation $1/Tg = w_1/T_{g_1}+w_2/T_{g_2}$ to be obeyed, where w_1 and w_2 are the weight fractions of the two components, and Tg_1 and Tg_2 the glass temperatures of the respective homopolymers, the required glass temperature for poly-(vinylidene fluoride) would be about 15° lower than observed. The effect of crystallization on the glass temperature of a copolymer will also be discussed.

* Supported in part by the Quartermaster Research and Development Command, Rubber Branch.

J7. Dilatometric Measurements on Gels of Cellulose Tributyrate and Cellulose Nitrate. M. N. VRANCKEN AND JOHN D. FERRY, *University of Wisconsin.*—The thermal expansion of gels of cellulose tributyrate in dimethyl phthalate and cellulose nitrate in diethyl phthalate has been studied over a temperature range from 155°K to room temperature, using Pyrex dilatometers with long capillary tubes and 2,3-dimethyl pentane as a confining liquid. Values of the glass transition temperatures (T_g) and of the thermal expansion coefficients above and below T_g have been determined. For cellulose tributyrate gels, T_g decreases with decreasing polymer concentration. Below 20% polymer, measurements became impossible, because of partial freezing out of solvent. For cellulose nitrate, over a concentration range from 37% to 12%, T_g goes through a minimum with decreasing polymer concentration.

J8. Hydrodynamic and Thermal Behavior of a Plastic Column. S. BROERSMA, *Northwestern University.*—The low value of Reynold's number and the low heat conductivity make it necessary to analyze the flow of hot plastic on the basis of a layer system. Thus a roll resting on two calenders, one of which is at rest, can be divided into a center core, an outside layer penetrating the nip and a thin coating sheared off by the web. The observed flow pattern of the longlived core can be understood on the basis of Newtonian hydrodynamics. Taking into account an exponential temperature dependence of the viscosity, instabilities in the temperature are theoretically predicted. The time constant is of the order of an hour. Most of the heat development and force action takes place in the outside layer reaching deep into the nip. The fact that the bare rolls do not allow plastic to pass indicates that the increase in shear stress with depth cannot be matched by outside forces so that sliding does occur. The relationship observed between the force keeping the rolls together and the thickness of the film passing with the web can be explained with a viscosity varying as $(\tau_0/\tau)^n \exp -p/p_0$. In the case of polyethylene, $\tau_0=0.5$ atmos, $n=1$, $p_0=50$ atmos apply. Irregularities in the plastic coating affecting a technical process, can be related to the existence of layers of different temperature.

J9. Kinematographic Study of Tensile Fracture in Polymers. A. M. BUECHE AND A. V. WHITE, *General Electric Research Laboratory.*—High-speed motion pictures were taken of silicone rubber, irradiated polyethylene, Plexiglas II, and aluminum foil while they were being broken. Fractures started internally in some of the silicone samples but at the edges of all of the others. The rates of crack growth and the rates of retraction of the ends of the rubber samples were measured. The velocities with which the cracks grew were compared with the results of the theories of Poncelet and Yoffe. Their prediction, that the velocities should be about one-half those of transverse waves in the media, was found to represent the data for materials with moduli differing by five decades. After fracture, the ends of the rubber samples contracted with velocities approximately equal to the velocities of longitudinal waves in these samples.

FRIDAY MORNING AT 9:30

Mellon Institute Auditorium

(W. D. KNIGHT presiding)

Nuclear Magnetic Resonance, Paramagnetic Resonance, Ferromagnetic Resonance

K1. Knight Shift in Metallic Sodium under High Hydrostatic Pressure. G. B. BENEDEK, N. BLOEMBERGEN, AND T. KUSHIDA, *Harvard University.*—Measurements of the pressure dependence of the Knight shift in metallic sodium under hydrostatic pressure have been carried out in the range 1-10 000 kg/cm² using a beryllium copper bomb. The sodium resonance frequency was measured with a Pound-Watkins type spectrometer by beating it against a multiple of an extremely stable (1 part in 10^9) 100 kc frequency standard. The magnetic field was stabilized using the proton resonance in an external sample. It was found that at 6.710 mc the resonance frequency in metallic sodium decreases by 135±15 cps for 10 000 kg/cm². Using the value $\Delta\nu/\nu=0.113$ for the Knight shift at atmospheric pressure and room temperature, one finds that $\Delta\nu/\nu$ is decreased by 1.8±0.2% at 10 000 kg/cm². If Bridgman's compressibility data are used, the experimental results can be decribed satisfactorily by $\Delta\nu/\nu=0.113(V/V_0)^{0.15\pm0.02}$ over the entire pressure range. Using the free electron model in which the effective mass is assumed independent of volume, one finds

$$\langle|\psi_F(0)|^2\rangle=\text{const}(V/V_0)^{0.52\pm0.02}.$$

On the other hand, using the Pines collective electron model for the spin susceptibility, one finds

$$\langle|\psi_F(0)|^2\rangle=\text{const}(V/V_0)^{0.50\pm0.02}.$$

K2. Nuclear Magnetic Resonance Measurements of the Electronic Specific Heat. DAVID PINES, *Princeton University.*—Nuclear resonance measurements of T_1 and $(\Delta H/H)$ in metals, when combined with theoretical calculations of the electron spin susceptibility, provide quite useful information concerning the electronic specific heat. Consider the Korringa relation,[1] revised to take into account the effects of exchange and correlation on the electron specific heat and spin susceptibility.[2] We have

$$T_1(\Delta H/H)^2=(\hbar/4\pi\kappa T)(\gamma_e/\gamma_n)^2(C_0/C_e)^2(\chi_e/\chi_0)^2,$$

where T_1 is the nuclear relaxation time due to the hyperfine interaction with the conduction electrons, and we have assumed equal densities of up and down spin electrons. C_e and χ_e are the electronic specific heat and spin susceptibility in a gas of *interacting* electrons, C_0 and χ_0 the corresponding free electron values. This relation, together with a theoretical calculation[2] (or experimental measurement) of (χ_e/χ_0), yields a maximum value of (C_e/C_0), maximum because in neglecting other relaxation mechanisms, we may choose a T_1 which is too short. Results will be given for the particularly interesting case of the alkali metals, for which the electron effective mass is known, and the electronic specific heat is otherwise difficult to measure.

[1] J. Korringa, Physica **16**, 601 (1950).
[2] D. Pines, *Solid State Physics* (Academic Press, Inc., New York, 1955), Vol. I.

K3. Electron Spin Resonance and Magnetic Susceptibility Experiments on Dilute Alloys of Mn in Cu. C. KITTEL, J. OWEN, M. BROWNE, V. ARP, AND A. F. KIP, *University of California, Berkeley.*—Dilute alloys of Mn in Cu are expected to show marked effects of the exchange interaction between the $3d^5$ ion core electrons of the Mn atoms and the 4*s* conduction electrons of the crystal. The simple model leads to the prediction of indirect exchange ferromagnetism; electronic Knight shift of the electron spin resonance line; nuclear Knight shift of the copper nuclear resonance; electron spin relaxation by the coupling with the conduction electrons; and anomalous electrical resistivity by the Elliott-Schmitt mechanism. It is actually observed that all of these effects are weaker than would be expected by one or two orders of magnitude. It is as if the Mn dissolved as a neutral atom, giving no electrons to the conduction band. This picture leads to a weak exchange coupling; it is not inconsistent with the phase diagram of the Cu–Mn system contrasted with the Cu–Zn system which has the same number of 4*s* electrons. The alloys appear to be antiferromagnetic.

K4. Nuclear Resonance Experiment on Dilute Cu-Mn Alloy. W. D. KNIGHT, *University of California, Berkeley.*—The nuclear resonance of Cu^{63} was observed in an unannealed alloy of 0.03 atomic percent manganese in copper. The value of the magnetic field was 5200 oersteds. The results are compared with those for pure copper at several temperatures. At 1.2°K the resonance frequency in the alloy is 1.0±1 kc lower than for pure copper. This effect is quite small; the magnitude and direction are approximately what one expects from a demagnetizing factor. One concludes from this result that the magnetization of the conduction electrons, as seen by the copper nucleus, is substantially the same as for pure copper. The presence of the Mn is strongly apparent, however, as an effect on the line width in the alloy, which is 25 kc at 1.2°K. This is to be compared with 7.5 kc for pure copper.

K5. Spin-Spin Relaxation in Systems with Two Magnetic Ingredients.* A. M. PORTIS, *University of Pittsburgh.*—Spin-spin relaxation has been investigated theoretically for systems like *F*-centers in alkali halides or donor centers in semiconductors, which have the following salient features: (1) the effect of the nuclear spins on the electron spins may be described by a resonance spectrum, (2) each electron spin may be identified with a definite position in the spectrum, (3) the electron spins are randomly distributed through the lattice, and (4) the position of an electron in the lattice and its position in the resonance spectrum are completely uncorrelated. The interaction between electron spins is treated by time-dependent perturbation theory and an expression for the life of an individual spin state is found. This time, τ_S equals $\Delta\omega/\Delta^2$, where Δ is a measure of the strength of the spin-spin interaction and $\Delta\omega$ is related to the width of the resonance spectrum. Macroscopic spin-spin relaxation is described in terms of the diffusion of spin excitation through the resonance spectrum. The behavior of the spin system in an rf field has been investigated by the substitution of a diffusion term for the usual spin-spin term in the Bloch equations. A characteristic diffusion time $\tau_D=(\gamma H_1\tau_S)^2\tau_S$ is found.

* This research was supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

K6. Paramagnetic Resonance Investigation of Irradiated KCl Crystals Containing *U*-Centers.* B. SMALLER, P. H. YUSTER, AND C. J. DELBECQ, *Argonne National Laboratory.*—The paramagnetic resonance technique has been used to investigate the properties of KCl crystals containing *U*-centers. The bleaching of *U*-centers by ultraviolet light has been presumed to proceed by the net reaction $h\nu+U\rightarrow F+H^0$. After irradiation at 77°K the paramagnetic spectra revealed a doublet line having the characteristics of atomic hydrogen ($I=\frac{1}{2}$) along with the *F*-center resonance line. Verification of

the source of the structure was made by substitution of deuterium gas for hydrogen in the U-center preparation. The expected triplet ($I=1$) appeared in place of the doublet, the component separation in both cases was approximately that of the free atom. Phase selection of the field modulation permitted either H^0 or F to be preferentially observed. Annealing studies were made and correlated with similar properties in the optical absorption spectra. Bleaching in the F-band resulted in reduction of both F and H^0 signals.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

K7. Optical Investigation of Irradiated KCl Crystals Containing U-Centers.* C. J. DELBECQ, P. H. YUSTER, AND B. SMALLER, *Argonne National Laboratory.*—Along with the previously described paramagnetic resonance absorption investigation of KCl crystals containing U-centers, a parallel investigation of the optical absorption spectrum was carried out. A short irradiation of a KCl–KH crystal at $-80°$K with the unfiltered light from an AH-4 mercury lamp is found to bleach the U-band markedly while a very broad band (U_1) extending to the long wavelength side of the U-band is formed; very few F-centers are formed. Upon prolonged irradiation the F-band and a new band (U_2) with peak at 236 mμ are observed to grow. Irradiation of such a crystal (1) in the F-band, reduces the F- and U_2-bands by 25–50% and increases the U_1-band somewhat, or (2) in the U_1-band, reduces the U_1-band somewhat and increases the F- and U_2-bands by 25–50%. Evidence will be presented which indicates that the U_1-band is due to absorption by interstitial hydride ions, and that the U_2-band is due to the presence of interstitial hydrogen atoms in the lattice.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

K8. Zeeman Splitting of Acceptor States.* W. KOHN, *Carnegie Institute of Technology,* AND J. M. LUTTINGER, *University of Michigan.*—The interaction between a magnetic field and the orbital motion of impurity electrons or holes is in general enhanced by a factor of the order of m/m^* compared to that of free electrons describing a similar orbit. A calculation of the Zeeman splitting of the fourfold degenerate ground state of a hole bound by an acceptor ion in Ge has been carried out. This splitting depends critically not only on the mass parameters determined by the usual cyclotron resonance experiments but also on 2 additional parameters.[1] Measurements of the low-temperature susceptibility of acceptor states in Ge, which is proportional to the square of this splitting, should provide valuable information concerning the magnitude of these parameters. With reasonable choices of their values, the susceptibility is several times as large as that of a free electron spin.

* Supported in part by the Office of Naval Research.
[1] These also play an important role in the quantum theory of cyclotron resonances [J. M. Luttinger (to be published)].

K9. Relaxation Effects in Donor Spin Resonance Experiments in Silicon. G. FEHER AND R. C. FLETCHER, *Bell Telephone Laboratories.*—The spin relaxation time T_1 of electrons localized on donors in silicon was measured at 9000 mc in the temperature range between 1.2°K and 4°K for different donor concentrations. The longest relaxation time was associated with the purest samples investigated. For a doping of (10^{16}) phosphorus atoms/cm^3 T_1 was of the order of a minute. The relaxation time decreased with increasing impurity concentration and reached a value of less than 10^{-5} sec at (5×10^{17}) phosphorus atoms/cm^3. Free carriers were found to be very effective in reducing the relaxation time. This was demonstrated by shinning light on a sample which had initially along relaxation time. The free carriers thereby produced reduced the relaxation time by several orders. It is possible that carriers contributing to the impurity band conduction are responsible for the strong dependence of the relaxation time on donor concentration. Experimental techniques used to study the unusually long relaxation times involved will be discussed.

K10. Electron Spin Resonance in Heat-Treated Silicon. R. C. FLETCHER AND G. FEHER, *Bell Telephone Laboratories.*—Fuller[1] *et al.* have reported resistivity changes in silicon following a heat treatment of several hours at temperatures of 350–500°C. It was not known whether these changes were attributable to lattice defects or to impurities or both. In an attempt to identify the introduced donor, we have looked for a spin resonance in this heat-treated silicon. An arsenic-doped silicon sample, original resistivity of 8Ω-cm was heat treated by Fuller to give a final resistivity of 0.5Ω-cm. This sample gave a single resonance line with no evidence of hyperfine structure. Within the accuracy of the measurements the g-factor and line width are the same as have been observed for lithium impurities.[2] Although this cannot serve as complete identification, because of the absence of hyperfine structure, it is in agreement with the observation of Morin *et al.* that the heat treatment introduces an energy level which is identical with lithium.[3]

[1] Fuller, Ditzenberger, Hannay, and Buehler, Phys. Rev. **96**, 833 (A), (1954); Acta Metallurgica **3**, No. 1 (1955).
[2] A. Honig and A. F. Kip, Phys. Rev. **95**, 1686 (1954).
[3] Morin, Maita, Shulman and Hannay, Phys. Rev. **96**, 833 (A) (1954).

K11. Ferromagnetic Resonance in Thin Disks of Manganese Ferrite. J. F. DILLON, JR., *Bell Telephone Laboratories.*—Ferromagnetic resonance line shape in disks was studied as suggested by recent theoretical work.[1] Disks of various sizes, orientations, and aspect ratios (~0.06) were cut from a manganese ferrite single crystal.[2] Experiments were performed with these samples in microwave cavities with the steady field: (a) normal to, or (b) in the plane of the disks. Spheres of the same material have also been studied for comparison. Most of the work was done at 9300 Mc. In case (a) the curve of absorption *versus* field [$\mu''(H)$] shows a series of peaks which increase in height and separation with increasing field up to the principal absorption, above which there is practically no structure. In case (b) there is structure above and below the main peak. The shape of $\mu''(H)$ for spheres and for various disks in cases (a) and (b) will be compared. There is a variation in the absorption curve with rf field configuration.

[1] Clogston, Suhl, Walker, and Anderson, Phys. Rev. (to be published).
[2] Grown by R. W. Kebler, Linde Air Products Company.

K12. Resonant Modes of Ferromagnetic Spheroids. L. R. WALKER, *Bell Telephone Laboratories.*—Under appropriate conditions additional absorption peaks may be observed in ferromagnetic resonance experiments at dc magnetic fields higher or lower than the Kittel value for the spatially uniform mode.[1] Consider small disturbances of the uniform dc magnetization whose "wavelength" is comparable with sample size. For a wide range of sample dimensions (10^{-4} cm – ~10^{-1} cm) the frequency of such modes is shape, but not size dependent, since the effects of exchange and electromagnetic propagation, which involve distances, may be ignored simultaneously. The characteristic equation for these modes in arbitrary spheroids in free space (axis along the dc magnetic field) is obtained by applying the ordinary magnetostatic boundary equations to the ac **H** and **B**; the latter being obtained by solving the linearized equations of motion. Numerical solutions have been found for several cases. The modes are identified systematically by three integers associated roughly with angular and radial variation. Frequencies or fields are found on either side of the Kittel values, but the frequency never lies below the extrapolated long-wavelength limit of the spin wave spectrum.

[1] White, Solt, and Mercereau, Bull. Am. Phys. Soc. Ser. II, **1**, 12 (1956); preceding abstract.

K13. Comparison of Experiment and Theory in Antiferromagnetic Resonance. ROALD K. WANGSNESS, *U. S. Naval Ordnance Laboratory.*—It is possible to test some of the details of the semiclassical theory of antiferromagnetic resonance[1] by using data obtained from resonance experiments on single crystals below the Curie temperature. The theory leads directly to the following relation involving only experimentally determined quantities:

$$(\alpha H_{\parallel}^2+H_{\perp}^2)/(H_{\parallel}H_p)=1+\alpha.$$

In this expression, $\alpha=1-(\chi_{\parallel}/\chi_{\perp})$, $H_p=\omega/\gamma$ is the resonance field in the paramagnetic state, while $H_{\parallel}$ and $H_{\perp}$ are the fields for which resonance is obtained when the constant field is respectively parallel and perpendicular to the direction of spin alignment. The only suitable experimental data[2] presently available are those obtained by McGuire from a single crystal of Cr_2O_3, and it will be shown that they are in good agreement with the foregoing relation.

[1] T. Nagamiya Progr. Theoret. Phys. Japan **6**, 350 (1951); F. Keffer and C. Kittel, Phys. Rev. **85**, 329 (1952).
[2] McGuire, Scott, and Grannis, Phys. Rev. **98**, 1562 (A) (1955); Phys. Rev. (to be published).

K14. Line Width in Mn Ferrite Single Crystals.* P. E. TANNENWALD, *Lincoln Laboratory.*—The full width at half-maximum absorption, ΔH, has been measured in a single crystal of MnZn ferrite as a function of temperature at 9100 Mcps. The behavior of ΔH is remarkable in that it increases from its minimum value of 56 oersteds at room temperature to a maximum of 700 oersteds at 15°K, and then decreases again to 240 oersteds at 1.3°K. The new data fill the gap between 4.2°K and 77°K,[1] and show the presence of a pronounced peak in the relaxation. This peak is also present at the same temperature at 24 000 Mcps. The anisotropy undergoes no drastic change in this temperature region. This behavior is to be contrasted with MnFe ferrite (small Fe^{++} impurity), whose ΔH is a maximum of 265 oersteds near room temperature, decreases to 160 oersteds at 4.2°K and also decreases to 75 oersteds at its Curie temperature of 590°K. This difference in magnitude and location of the maximum relaxation may be related to differences in the magnetoelastic coupling.

* The research reported in this document was supported jointly by the U. S. Army, the U. S. Navy, and the U. S. Air Force under contract with the Massachusetts Institute of Technology.
[1] P. E. Tannenwald, Phys. Rev. **100**, 1713 (1955).

FRIDAY MORNING AT 9:30

Mellon Institute Social Room

(R. C. FLETCHER presiding)

Various Topics in Semiconductor Physics

L1. Infrared Absorption in *n*-Type Silicon.* W. G. SPITZER AND H. Y. FAN, *Purdue University.*—Unlike carrier absorption in *p*-type silicon, which increases smoothly as λ^2, absorption beyond the intrinsic edge in *n*-type crystals rises to a flat region extending from 2 to 5 microns. Then it increases almost as λ^2 toward longer wavelengths. The spectrum can be considered as a band superimposed on a smooth curve. Similar spectrum has been observed in single crystals doped with arsenic or antimony.[1] Early measurements of Becker on a polycrystalline *n*-type crystal showed the same behavior. The magnitude of the absorption increases with the conductivity of the sample. Measurements have been made also at liquid-nitrogen and liquid-helium temperatures. The band remains about the same. The results suggest that the absorption band corresponds to excitation of conduction electrons or electrons on donor impurities to higher energy bands. Attempts to observe the growth of the absorption band as the samples were heated to the intrinsic range did not yield conclusive results, the absorption becoming dominated by holes. Thus the possibility of the band being caused by deep lying levels in the forbidden gap has not yet been definitely ruled out.

* Work supported by an Office of Naval Research contract.
[1] Two antimony-doped crystals were supplied by Philco through Dr. E. H. Borneman, one arsenic-doped crystal was supplied by Raytheon through Dr. P. Debye, and one by Westinghouse through Mr. R. E. Davis.

L2. Infrared Absorption in Tellurium.* R. S. CALDWELL AND H. Y. FAN, *Purdue University.*—The study of absorption in tellurium single crystals[1] has been extended to 150 microns. Residual rays were used for wavelengths over 40 microns. Two peaks in the absorption spectrum were observed at around 52 and 94 microns. Measurements made on various samples at 78°K showed that in addition to the two bands there is an absorption increasing steadily with wavelength; the latter varied with carrier concentration whereas the two bands remained roughly the same in all samples, with peak absorption $\sim$60 cm^{-1}. The bands can be therefore attributed to lattice absorption. The symmetry of tellurium structure does not give normal modes active for radiation polarized with $E \parallel C$-axis. The 52-micron band was measured at room temperature using polarized radiations, both with $E \parallel C$-axis and with $E \perp C$-axis. No significant difference was observed, indicating that the band is associated with combination modes. Two additional weak bands were observed at 24.5 and 28 microns.

* Work supported by a Signal Corps Contract.
[1] R. S. Caldwell and H. Y. Fan, Phys. Rev. **94**, 1427 (A) (1954).

L3. Infrared Absorption Spectra of *n*-type Impurities in Silicon. G. S. PICUS, E. BURSTEIN, AND B. W. HENVIS, *U. S. Naval Research Laboratory.*—Measurements at liquid-helium temperature of the infrared absorption spectra of P-, As-, and Sb-doped samples of silicon obtained from the Bell Telephone Laboratories yield the following values for the discrete absorptions due to the excitation of these impurity centers: P, 0.0395, 0.0446, and 0.0472 ev; As, 0.0421, 0.0474, 0.0506, and 0.0521 ev; and Sb, 0.0365 and 0.0399 ev. In taking differences of the energies of these lines, three characteristic values appear: $\Delta E \sim 0.0050$, 0.0030 and 0.0018 ev. The first two differences agree well with the values calculated by Kohn and Luttinger[1,2] for the level separations $(2p,m=\pm1)-(2p,m=0)$ and $(3p,m=\pm1)-(2p,m=\pm1)$, respectively. Combining our data with the calculated values of the separation of the various excited states from the conduction band gives the following optical ionization energies: P, 0.050 ev; As, 0.053 ev; and Sb, 0.043 ev.

[1] W. Kohn and J. M. Luttinger, Phys. Rev. **97**, 1721 (1955).
[2] W. Kohn, Phys. Rev. **98**, 1856 (1955).

L4. Intrinsic Optical Absorption in Germanium-Silicon Alloys. R. BRAUNSTEIN AND S. M. CHRISTIAN, *RCA Laboratories.*—Single crystals of Ge-Si alloys were grown in the

range from 0 to 30% Si in Ge and 0 to 10% Ge in Si. The intrinsic absorption spectra have been measured as a function of temperature in the low-absorption region (i.e., K less than 100 cm^{-1}). The data for samples with Si content less than 10% and Ge content less than 5% can be analyzed in terms of an indirect transition model with a single set of conduction minima. However, in the range of 14 to 19% Si in Ge, the data cannot be analyzed in terms of a single set of conduction minima in the reduced zone, but require the participation of two sets of minima. It is in this range of composition that the optical band gap curve *vs* composition reported by Johnson and Christian[1] shows an abrupt break. Herman[2] has suggested that in this range of composition the conduction band minima along the [111] axes in the reduced zone, characteristic of Ge and the [100] minima, characteristic of Si are within kT of each other. The optical energy gap was found to diminish nonlinearly with composition in the range from 0 to 5% Ge.

[1] E. R. Johnson and S. M. Christian, Phys. Rev. **95**, 560 (1954).
[2] F. Herman, Phys. Rev. **95**, 847 (1954).

L5. Free Carrier Absorption for High Impurity Concentrations. EVAN O. KANE, *General Electric Research Laboratory.*—The p-type germanium free carrier absorption data of R. Newman[1] have been analyzed in the range of impurity concentration greater than 10^{17}/cc. The change of shape of the absorption curves can be attributed to three causes: (1) a change in energy band shape due to the added impurity, (2) the motion of the Fermi level, (3) the occurrence of indirect optical transitions resulting from impurity scattering. The impurity effects have been analyzed by perturbation theory using an interaction potential similar to that used in the Brooks-Herring treatment of the mobility. The change in energy band shape is found to have a very small effect on the absorption. The motion of the Fermi level has a very significant effect in shifting the absorption peak to higher energies. The effect of indirect transitions is chiefly to increase the absorption in the high-energy tail. The magnitudes of the effects are consistent with experiment.

[1] R. Newman and W. W. Tyler, Bull. Am. Phys. Soc. Ser. II, **1**, No. 1, 49 (January, 1956).

L6. Optical Absorption in Semiconducting Diamond. H. J. STEIN, M. D. BELL, AND W. J. LEIVO, *Oklahoma A. & M. College.*—The optical absorption in type IIb diamond was determined to obtain information on the nature of the imperfections responsible for the high electrical conductivity.[1] Measurements were made covering the range from the fundamental absorption in the ultraviolet to 13μ. Maxima of infrared bands occurred at 5.07, 4.93, 4.62, 4.07, 3.56, 3.13, and 2.75μ. Weak absorption of variable intensity extends from 1μ to 2.55μ. From electrical conductivity measurements, the slope of $k \ln\sigma$ *vs* $1/T$ has a value 0.35 ev.[2] This can be associated with an activation energy of 0.70 ev which corresponds to 1.8μ. A group III or V-impurity should give a band around 3.1μ. In the visible and ultraviolet regions, absorption starts around 7000 A and increases gradually until 2500 A, at which point absorption increases rapidly as the fundamental absorption band is reached, Essentially complete absorption occurs at 2220 A. We thank Dr. Custers for furnishing the rare diamond.

[1] J. F. H. Custers, Physica **20**, 183 (1954).
[2] J. F. H. Custers, Nature **176**, 173 (1955); J. Brophy, Phys. Rev. **99**, 1336 (1955); R. Smoluchowski and W. J. Leivo, Phys. Rev. **98**, 1532 (1955).

L7. Transient Photoconductivity Measurements in Germanium Containing Double-Acceptor Impurities. W. W. TYLER AND H. H. WOODBURY, *General Electric Research Laboratory.*—Measurements of the temperature dependence of photoconductivity decay times have been made for Ge crystals containing double-acceptor impurities (Fe, Co, Ni, Mn). In low-resistivity p-type samples such impurities act as recombination centers; at low temperatures the important constant is the capture cross section for electrons by neutral impurities ($\sigma \sim 10^{-15}$ to 10^{-16} cm^2). For low-resistivity n-type samples at low temperatures, the double-acceptor impurities are doubly charged negatively in equilibrium and thus act as hole traps; the cross section for the subsequent capture of electrons at the singly-charged negative sites is small due to Coulomb repulsion. Decay times in the n-type samples increase as the temperature is lowered with the temperature dependence determined either by activated recombination at the site of the trapped hole or more probably by evaporation of trapped holes with subsequent recombination at surfaces or other uncontrolled centers. Experimental results will be presented for n-type Mn-doped crystals for which hole evaporation with an activation energy of 0.3 ev seems to be the limiting process. With this interpretation, the capture cross section for electrons at singly-charged negative Mn sites is $<10^{-22}$ cm^2.

L8. Photoconductivity in Gold-Doped Germanium.* LEO F. JOHNSON, *Syracuse University.*—The photoconductive response of p-type gold-doped germanium extends the absorption data of Dash and Newman[1] to a value of 10^{-2} cm^{-1} for the absorption coefficient of pure germanium, and places the intrinsic edge for indirect transitions at 1.85 microns (0.67 ev) at 77°K. Low-level pulsed light measurements of the wavelength dependence of time constant reveal that for values of the absorption coefficient in the intrinsic region of less than 10 cm^{-1} (beyond 1.5μ), recombination of generated hole-electron pairs occurs via gold centers in both n- and p-type material (gold concentration $\sim 10^{14}$ atoms/cm^3). In p-type samples, electrons are captured by neutral gold atoms (capture cross section $\sigma \sim 2\times10^{-15}$cm^2), holes by Au$^-$ atoms ($\sigma \sim 2\times10^{-16}$ cm^2), both ground state lying at the lower gold acceptor level ($\sim$0.13 ev above the valence band) and both lifetimes being less than 10 μsec. In n-type samples, electrons may be captured by Au$^-$ atoms ($\sigma \sim 10^{-15}$ cm^2) with a lifetime of 20 μsec, and holes by Au^{--} atoms, with a lifetime of less than 10 μsec, both ground states lying at the upper acceptor level (0.20 ev below the conduction band). In addition, excitation from the lower level to the conduction band leads to a lifetime for electrons $\sim$10 msec.

* Supported by Wright Air Development Center.
[1] W. C. Dash and R. Newman, Phys. Rev. **99**, 1153 (1955).

L9. Recent Studies of Deep Impurity Levels in Germanium. H. H. WOODBURY AND W. W. TYLER, *General Electric Research Laboratory.*—Cadmium has been observed to act as a double-acceptor impurity in germanium introducing impurity levels which have tentatively been placed at 0.06 ev and 0.2 ev from the valence band. These are about a factor of two deeper than the impurity levels introduced by Zn[1] in Ge. With conventional crystal growth techniques, the rate of Cd evaporation from the Ge melt is much greater than for Zn. For normal growth rates the loss is so rapid that Cd concentration in the crystals varies appreciably in distances comparable with sample dimensions, making it difficult to obtain homogeneous samples for Hall coefficient studies. In order to improve sample homogeneity and to obtain accurate values of the distribution coefficient for Cd in Ge, ingots have been grown in a horizontal boat in a closed system which precludes loss of Cd. At present only a lower bound of 5×10^{-6} has been established for the distribution coefficient; the maximum Cd concentration observed on single crystals of Ge is 6×10^{14} cm^{-3}. In addition to Cd results, recent studies of Ge crystals doped with Ag and Pt will be presented.

[1] H. H. Woodbury and W. W. Tyler, Phys. Rev. **100**, 1259 (A) (1955).

L10. Gold-Doped Silicon. C. B. COLLINS AND R. O. CARLSON *General Electric Research Laboratory.*—Measurements of the

temperature dependence of the resistivity and Hall coefficient for *n*- and *p*-type gold-doped silicon crystals show a new acceptor level at 0.55 ev from the conduction band and and a donor level[1] 0.35 ev from the valence band. A level previously reported[2] 0.3 ev from the conduction band was not observed. A search was made for levels associated with doubly-charged gold centers but none were found. On exposure to intrinsic light at 145°K, *p*-type gold-doped silicon converts to *n*-type indicating hole trapping. Similar measurements on *n*-type gold-doped silicon show a small increase in mobility. The distribution coefficient of gold in silicon has been measured and found to be in substantial agreement with previous work.[1] Heat treating at 500°C and at 1000°C for 40 min in each case produced no observed change in the gold-doped samples.

[1] E. A. Taft and F. H. Horn, Phys. Rev. **93**, 64 (1954).
[2] J. A. Burton, Physica **XX**, 845–854 (1954).

L11. New Determination of Silicon Band Gap. R. O. CARLSON, C. B. COLLINS, AND C. J. GALLAGHER, *General Electric Research Laboratory.*—The addition of gold to *n*-type silicon introduces a deep acceptor level above the middle of the forbidden band. If gold is the dominant impurity, the Fermi level E_F will be at a position relative to the gold acceptor level E_1 given by[1]

$$E_F = E_1 - kT \ln \frac{N_1 - N_2}{2N_2},$$

where N_1 is the gold concentration and N_2 the net shallow level donor concentration. Since E_1 is close to the middle of the forbidden band, it is possible by increasing the gold to donor ratio to drive the Fermi level from one side of the middle to the other, making it possible to observe the same level in both *n*- and *p*-type silicon. The activation energy of the gold acceptor level was measured from the temperature dependence of resistivity and Hall coefficient and is 0.55 ev relative to the conduction band and 0.58 ev relative to the valence band. The band gap of silicon at absolute zero as deduced from these values is 1.13 ev.

[1] W. Shockley, *Electrons and Holes in Semiconductors* (D. Van Nostrand Company, Inc., New York, 1950), pp. 471–475.

L12. Observation of Short Carrier Lifetimes. G. K. WERTHEIM, *Bell Telephone Laboratories, Inc.*—Lifetime and trapping phenomena on a time scale of 10^{-8} to 10^{-5} seconds have been observed in germanium and silicon following pulsed excitation of duration 2×10^{-8} sec, having a rise and cutoff short compared to this interval. The pulse source is a Van de Graaff accelerator delivering a pulse peak power of 45 w at a low repetition rate. Data are obtained from a CRT display. Questions of bombardment damage, utilization of the energy of the primary electrons, equivalence of bombardment, and photoconductivity will be briefly discussed. Results obtained with a number of materials exhibiting an effective lifetime shorter than 10^{-6} sec will be presented.

L13. A Simplified Theory of Space-Charge-Limited Currents in an Insulator with Traps. MURRAY A. LAMPERT, *RCA Laboratories.*—An ohmic contact between a metal and an insulator permits the injection of electrons into the insulator. Subsequent flow of the electrons is space-charge limited. In real insulators the trapping of electrons in localized states in the forbidden gap profoundly influences the current flow. The interesting features of the I–V characteristic are confined within a triangle in the log I–log V plane bounded by three limiting curves: Ohm's law, Child's law for solids ($I \propto V^2$) and a traps-filled-limit curve which has a voltage threshold and an enormously steep current rise. Simple inequalities relating the true field at the anode to the ohmic field facilitate qualitative discussion of the I–V characteristic. Exact solutions have been obtained for an insulator with a single, discrete trap level in a simplified theory which idealizes the ohmic contact and neglects the diffusive contribution to the current, both reasonable approximations. The type of nonlinearity (resembling dielectric breakdown but actually reversible) discovered by Rose[1] to arise from traps distributed in energy is shown to exist for the discrete-level traps also.

[1] A. Rose, Phys. Rev. **97**, 1538 (1955).

L14. Giant Traps. MELVIN LAX, *Bell Telephone Laboratories and Syracuse University.*—The enormous cross sections ($>10^{-13}$ cm^2) observed by Haynes and Hornbeck[1] for electrons in *p*-type silicon can be explained by capture into the hydrogen-like excited states of an attractive center. In view of the Bohr correspondence principle for highly excited states, the motion between collisions is treated classically. The theory extends the Thomson theory for three-body recombination of ions in gases. The cross section $\sigma(E_0, U)\,dU$ is calculated for collisions starting with positive energy E_0 and ending with a binding energy between U and $U+dU$. The total cross section is then written

$$\sigma(E_0) = \int \sigma(E_0, U) dU\, P(U),$$

where $P(U)$ is the probability that an electron will stick, i.e., that it will dribble down to the ground state before re-emerging The probability $P(U)$ of eventual capture is found by solving an integral equation describing the random walk of the electron up and down the energy scale with the boundary condition that, once an electron acquires a positive total energy, it has escaped. The result of this calculation is insensitive to the details of the trapping potential (other than its long range Coulomb tail).

[1] J. A. Hornbeck and J. R. Haynes, Phys. Rev. **97**, 311 (1955).

FRIDAY MORNING AT 9:30

Mellon Institute Conference Room

(F. SEITZ presiding)

Irradiation Effects on Metals

LA1. Influence of Neutron Bombardment on Cold-Worked and Carburized Iron Single Crystals. F. W. KUNZ, *Knolls Atomic Power Laboratory.**—Carburized and cold-worked single crystals of iron were irradiated near room temperature to a total flux of 10^{19} nvt to determine the effect of neutron irradiation on the mechanical properties of iron crystals hardened by other means prior to irradiation. The yield stress of the carburized crystals as measured from load *versus* elonga-

tion curves was increased approximately 50% after the neutron exposure, whereas in cold-worked crystals the hardening effect of the irradiation decreases with increasing amounts of cold work. Strain-aging studies on irradiated decarburized iron crystals indicate that no changes in yielding behavior or yield stress occur after the aging treatments. Marked changes were observed on strain-aging of irradiated carburized iron crystals. Possible interpretation of this investigation will be presented.

* The Knolls Atomic Power Laboratory is operated by the General Electric Company for the U. S. Atomic Energy Commission.

LA2. On the X-Ray Observation of Vacancy-Interstitial Pairs in Irradiated Cu.† ARNOLD H. KAHN, *University of Illinois.*—Calculations have been performed for the Bragg-Laue and diffuse reflections of irradiated Cu containing vacancy-interstitial pairs. It is assumed that the interstitials reside at the body-center position and that the defects are randomly located. The Bragg-Laue reflections with *hkl* all odd are multiplied by a factor 1–4 ($p-p^2$) where p is the concentration of pairs. The all-even reflections are not changed. The theory of Huang[1,2] was used for the diffuse scattering caused by the elastic distortion. The diffuse scattering should barely be visible. Lattice constant shifts[1,3] of the order of 0.05% per 0.1% of defect pairs should occur.

† Supported by the U. S. Atomic Energy Commission.
[1] K. Huang, Proc. Roy. Soc. (London) **A190**, 102 (1947).
[2] C. W. Tucker and P. Senio, Phys. Rev. **99**, 1777 (1955).
[3] J. D. Eshelby, J. Appl. Phys. **25**, 255 (1954).

LA3. Radiation Annealing of Cold-Worked Copper by 1.25 Mev Electrons.* C. J. MEECHAN AND H. NEELY, *Atomics International.*—Copper wires of 99.999% purity were cold worked by drawing through dies from a diameter of 0.016 inch to 0.015 inch. Subsequently, the wires were annealed at various temperatures above 150°C for several hours. They were then irradiated at 100°C with electrons of energy 1.25 Mev. In all cases, the irradiation caused the residual resistivity of the specimens to decrease. This decrease corresponds to a greater resistivity change than would have occurred thermally at higher temperatures. The magnitude of the decrease varied with the initial residual resistivity. Preliminary results are as follows: for $\rho=0.34\times10^{-8}$ ohm-cm, the resistivity decreased by 0.6%, and for $\rho=1.5\times10^{-8}$ ohm-cm, the resistivity decreased by 1.8%, after an integrated exposure of 1.2×10^{17} electrons/cm². No decreases were observed when the irradiation was performed with the specimen temperature held at 20°C. This effect is interpreted to be a result of thermally-induced migration of defects produced by the irradiation.

* This work was performed under contract with the U. S. Atomic Energy Commission.

LA4. Effect of Electron Bombardment and Quenching on the White-to-Gray Transformation in Tin. A. SOSIN, *North American Aviation, Inc.*—Fleeman and Dienes[1] have demonstrated that neutron bombardment at 78°K greatly enhances the white-to-gray transformation rate of tin subsequently held between −60°C and −20°C where relatively rapid transformation occurs. This work has been extended to electron bombardment (integrated flux of $3.5\times10^{+18}$ electrons/cm² near 78°K) and to quenching from 200°C. Electrical resistivity measurements at 4.2°K indicate a damage rate under this bombardment of 6×10^{-28} ohm-cm per electron/cm². Despite this, no evidence of transformation has been observed on specimens held in the transformation range for one week following irradiation or quenching. Furthermore, 12.5% of the resistivity recovered at 78°K overnight. These results are taken to indicate that single point defects or small aggregates formed by motion of these defects are insufficient to nucleate the transformation whereas displacement spikes[2] may serve as suitable nuclei. This is in agreement with the calculations of Cagle and Eyring.[3]

[1] J. Fleeman and G. Dienes, J. Appl. Phys. **26**, 652 (1955).
[2] J. A. Brinkman, J. Appl. Phys. **25**, 961 (1954).
[3] Cagle and Eyring, J. Phys. Chem. **57**, 942 (1953).

LA5. Effect of Heat Treatment and Neutron Irradiation on the Lattice Parameter of Alpha Brass. R. FEDER, A. S. NOWICK,* AND D. B. ROSENBLATT, *Frankford Arsenal.*—The room temperature lattice parameter of 70-30 alpha brass was measured after various thermal treatments. Powdered specimens quenched from 450°C show a decrease in lattice parameter of 0.006, 0.010, and 0.020% after annealing at temperatures of 200°, 150°, and 125°C, respectively. The 125°C value represents an anneal of 4000 hours, but a final value had not yet been attained. The relaxation times for these lattice parameter changes are in reasonable agreement with those previously obtained by Damask[1] by means of anelastic and resistivity measurements. Neutron irradiation at 50°C reduces the parameter by 0.02%. A characteristic equilibrium value of the parameter is attained at each anneal temperature regardless of previous thermal treatment or irradiation. From thermodynamic data for this alloy it is estimated that an observed lattice parameter change of 0.01% is ascribable to a change in the short-range order parameter of approximately 0.06.

* Permanent address: Yale University.
[1] A. C. Damask, J. Appl. Phys. (to be published).

LA6. On Radiation Induced Irreversible Changes in Metals. ROGER CHANG, *Rutgers University.*—Published experimental work[1–3] reveals that neutron irradiation (*a*) enhances the precipitation of iron in supersaturated solid solution of iron in copper, (*b*) increases slightly the amount of ferrite in stainless steels, and (*c*) induces secondary recrystallization (or grain growth) in polycrystalline copper and nickel. These observations could be interpreted in terms of the "displacement spike" hypothesis of radiation damage. Examples of semiquantitative correlation between theory and experiment will be described and pros and cons of the "displacement spike" hypothesis will be discussed.

[1] A. Boltax, U. S. Atomic Energy Commission Off-Site Conference on Solid-State Metallurgy, Carnegie Institute of Technology, June, 1955.
[2] M. B. Reynolds *et al.*, Trans. Am. Inst. Mining Met. Engrs. **203**, 555 (1955).
[3] S. T. Konobeevsky *et al.*, International Conference on the Peaceful Uses of Atomic Energy, United Nations, July, 1955.

LA7. On the Nature of Thermal Spikes. C. W. TUCKER, JR., AND P. SENIO, *Knolls Atomic Power Laboratory.**—Theoretical calculations suggest that the duration (10^{-11} sec) and smallest dimension (20 atom diameters) of thermal spikes in metals undergoing irradiation may be too small to permit the thermal nucleation and growth of crystals of a second phase even though the average "temperature" of the spike may be above the melting point. Experiments have been performed which show that even the very energetic fission thermal spikes are too rapid and small to permit the nucleation and growth of a second phase in uranium metal containing 2 atomic percent chromium. It is suggested that the terms "heated" and "melted" are not strictly appropriate to thermal spikes. Rather the region of a thermal spike should be regarded as a highly disturbed zone in which atomic interchange can occur, but which quickly returns to the structure and orientation of the surrounding crystal with a distribution of interstitials and vacancies which may then interact with each other or with other defects possibly present in the crystal.

* The Knolls Atomic Power Laboratory is operated by the General Electric Company for the U. S. Atomic Energy Commission.

LA8. Measurements of the Dependence of the Young's Modulus and Logarithmic Decrement of Copper Single Crystals upon Neutron Irradiation. D. O. THOMPSON AND D. K. HOLMES, *Oak Ridge National Laboratory.*—Measurements of the effects of room temperature neutron irradiation of copper single crystals of 99.999% purity have been made using an in-pile resonant bar technique. In all cases it has been observed that the irradiation increases the modulus and decreases the decrement.[1] Interpretations of the results can best be given in terms of an oscillating dislocation line mechanism in which the oscillations are suppressed by the presence of interstitial atoms, vacancies, or some combination thereof. Indeed, the results are in fairly good quantitative agreement with the predictions of Koehler's impurity pinning calculations.[2] With this interpretation it is shown that the results lead to generally accepted values for the dislocation densities and average segment lengths, and, consequently, that irradiation facilities provide a new and independent technique for the measurement of these quantities. Calculations show that effects similar to those of neutron bombardment may be expected from exposure to γ rays.

[1] Thompson, Holmes, and Blewitt, J. Appl. Phys. **26**, 1188 (1955).
[2] J. S. Koehler, *Imperfections in Nearly Perfect Crystals*, edited by W. Shockley (John Wiley and Sons, Inc., New York, 1952), p. 197.

LA9. Effect of Fast Neutron Irradiation on the Critical Shear Stress of Cu. D. K. HOLMES, J. K. REDMAN, T. H. BLEWITT, AND R. R. COLTMAN, *Oak Ridge National Laboratory.*—The critical shear stress of copper has been determined as a function of fast neutron bombardment and temperature. The test samples are single crystals of 99.999% pure copper and the measurements were performed on an Instron tensile machine. In general the effect of the irradiation is a marked increase in the critical shear stress, e.g., at room temperature a total fast neutron flux of 10^{19} neutrons/cm^2 sec results in an increase of the critical shear stress from 0.2 Kg/mm^2 to 3.40 Kg/mm^2. It has been found, empirically, that the critical shear stress at a given temperature tends to increase as the cube root of the integrated fast neutron flux. At various stages of irradiation the critical shear stress was measured at seven temperatures ranging from 4°K to 150°C; the variation with temperature is such that the data is fitted acceptably by a linear relationship between the critical shear stress and the square root of the absolute temperature. Some annealing studies have been made which indicate that the annealing process does not simply remove the effects of the neutron bombardment. The variation of the critical shear stress with the square root of the absolute temperature and with the cube root of the integrated fast flux may be understood on the basis of a model.

LA10. Very Low Temperature Irradiation of Metals; Energy Release at 35°K. T. H. BLEWITT, R. R. COLTMAN, T. S. NOGGLE, AND D. K. HOLMES, *Oak Ridge National Laboratory.*—Very low temperature irradiation of metals shows an annealing process at 35°K which may result from the annihilation of vacancy-interstitial pairs. Calorimetric measurements offer a sensitive tool to study this hypothesis as the formation energy of these defects is large (5 ev). The specific heat of copper single crystals was measured in the ORNL hole 12 cryostat following a 160–180 hour (4×10^{17} fast neutrons) bombardment at a temperature below 22°K. Dissipation of the nuclear heating (4×10^{-3} watts/g) in the sample was obtained through a combination of conduction (mechanical contact) and gaseous exchange (23 microns He) with the cryostat wall. Following a 12-hour evacuation of the sample chamber (0.01 microns) during the regular reactor shutdown (conduction maintaining the sample at 10°K) the reactor was raised to $\frac{1}{10}$ normal power and controlled by a boronated thermopile six inches from the sample. The gamma heating (4×10^{-4} watts/g) raised the temperature to 16°K. The sample was then isolated from the cryostat wall and the temperature measured as a function of time with a constant input of gamma heating uniformly absorbed within the sample. The specific heat given by the slope of the time-temperature curve was found to vary smoothly from 17°K to 50°K. It was possible to conclude that fewer than 5×10^{16} pairs per mole were annihilated.

LA11. Very Low-Temperature Irradiation of Metals; the Hole No. 12 Cryostat. R. R. COLTMAN AND T. H. BLEWITT, *Oak Ridge National Laboratory.*—From the results of recent radiation damage studies it has become apparent that low-temperature bombardments are of value towards a better understanding of the fundamental processes involved. A helium refrigerator was modified by the Arthur D. Little Company to meet the requirements of heat capacity and dependability necessary for low-temperature reactor bombardment work. It is estimated that the capacity for the machine is greater than 500 watts at 21.5°K. An aluminum cryostat 22 feet in length with a usable specimen chamber $1\frac{1}{4}$ in. i.d.$\times$24 in. long was constructed and inserted into vertical hole #12 in the ORNL graphite reactor. The machine, which uses helium as a refrigerant, circulates the cold gas through the sample chamber heat exchanger, which is located in the center of the reactor. The minimum temperature obtainable on the sample chamber wall at full reactor power is 10°K. Specimens are cooled by the use of helium exchange gas. Because of gamma-ray heating, specimen temperatures run somewhat higher than the wall temperature depending upon their density, geometry, and the exchange gas pressure. Uninterrupted operation at minimum temperature has been maintained on several runs of 180 hours. The fast neutron flux in this facility is 7×10 in. n/cm^2/sec.

LA12. Very Low-Temperature Irradiation of Metals: Change in Electrical Resistivity. J. K. REDMAN, T. S. NOGGLE, R. R. COLTMAN, AND T. H. BLEWITT, *Oak Ridge National Laboratory.*—The change in electrical resistivity of several metals has been measured during bombardment in the hole 12 cryostat at 19°K. All the samples showed that the change in resistivity was a linear function of the integrated neutron flux. The rate at which the resistivity increased with the flux was strongly dependent on the material. Copper (well-annealed single crystals of both high and relatively low purity, worked single crystals and polycrystals), gold, and α brass had their resistivity increased by about 1×10^{-26} ohm-cm/neutron; nickel and aluminum by about 3×10^{-26} ohm-cm/neutron; zinc, iron, and cobalt by about 9×10^{-26} ohm-cm/neutron; and partially ordered Cu_3Au by about 11×10^{-26}. It is not clear whether this variation is due to the binding energy or to the resistivity of a vacancy-interstitial pair. In the case of copper, assuming a scattering cross section of 2×10^{-6} ohm-cm per atomic percent of pairs and an isotropic neutron scattering cross section, the number of pairs formed is about 20%, that given by the Snyder-Neufeld calculation. Annealing studies were also made. In the region 30°–50°K about 40% of the induced resistivity was recovered in all cases except for iron, zinc, and Cu_3Au. It was apparent that this annealing reaction was not a single process of first or second order.

FRIDAY MORNING AT 9:30

Stephen Foster Auditorium

(J. G. DAUNT presiding)

DSSP Symposium on Low-Temperature Physics

M1. Frequency Dependence of Absorption in Electromagnetic Radiation by Normal Conductors and Superconductors. M. P. GARFUNKEL, *Westinghouse Research Laboratories.* (30 min.)

M2. Nonlocal Theories of the Supercurrent: Successes and Difficulties. A. B. PIPPARD, *Cambridge University (presently at University of Chicago).* (30 min.)

M3. Applications of Low-Temperature Specific-Heat Measurements to Some Solid-State Problems. S. A. FRIEDBERG, *Carnegie Institute of Technology.* (30 min.)

M4. Some Low-Temperature Properties of Color Centers. C. V. HEER, *Ohio State University.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Stephen Foster Auditorium

(C. C. KLICK presiding)

DSSP Symposium on Luminescence

N1. Theory of Activator Systems in Alkali-Halide and Zinc-Sulfide Phosphors. F. E. WILLIAMS, *General Electric Research Laboratory.* (30 min.)

N2. Radiation Resulting from Recombination of Holes and Electrons in Silicon. J. R. HAYNES, *Bell Telephone Laboratories.* (30 min.)

N3. Resonance Transfer Processes in Luminescent Systems. D. L. DEXTER, *University of Rochester.* (30 min.)

N4. Model for Monovalent Activators in the Sulfides. C. C. KLICK, *U. S. Naval Research Laboratory.* (30 min.)

N5. Luminescence and Photoconductivity. R. H. BUBE, *RCA Laboratories.* (30 min.)

FRIDAY AFTERNOON AT 2:00

132 Cathedral of Learning

(J. E. GOLDMAN presiding)

Ferroelectricity; Ferromagnetism, I

P1. Bridge for Accurate Measurement of Ferroelectric Hysteresis.* H. DIAMANT, K. DRENCK, AND R. PEPINSKY, *The Pennsylvania State University.*—A new instrument has been designed for the indistorted display of ferroelectric hysteresis loops even in the presence of relatively high conductivity. The electrical characteristics of a sample are determined directly from dial settings and meter readings. The basic circuit of the bridge may be described as two parallel Sawyer and Tower circuits, one containing the sample and the other containing resistors and capacitors for the compensation of conductivity and dielectric constant at saturation. The compensated hysteresis loop is displayed on an oscilloscope with the aid of a calibrated differential amplifier. The spontaneous polarization and the applied voltage, as well as the coercive field, are read on an electronic peak voltmeter. An important feature of the bridge is that measuremens are independent of the frequency and wave form of the applied voltage.

* Development supported by Signal Corps Engineering Laboratories and Wright Air Development Center.

P2. X-Ray Study of Nonferroelectric Phases of Rochelle Salt.* F. MAZZI, F. JONA, AND R. PEPINSKY, *The Pennsylvania State University.*—The crystal structure of the ferroelectric phase of Rochelle salt, space group $P2_1$, between $-18°C$ and $+23°C$, has been under x-ray and neutron examination.[1] In order to understand the nature of the two transitions, the structures of the two nonferroelectric phases have also been studied with x-rays, preparatory to neutron examination. Both nonferroelectric phases are in space group $P2_12_12$. Multifilm Weissenberg data with CuKα, and with specimens encased in Pyrex, were obtained at temperatures $-64°C$, $0°C$, and $+35°C$. Orthorhombic symmetry was assumed for all three phases, and six (001) projections were computed on X-RAC, employing as coefficients

$$F_{-64°C}^{obs.} - F_{+35°C}^{obs.}, \quad F_{-64°C}^{obs.} - F_{0°C}^{obs.},$$

and

$$F_{0°C}^{obs.} - F_{+35°C}^{obs.},$$

and

$$F_{-64°C}^{obs.}, \quad F_{0°C}^{obs.} \text{ and } F_{+35°C}^{obs.}.$$

Starting points for all phase assignments were the Beevers-Hughes[2] coordinates. Repeated refinement cycles led to R-factors of 10.5% for the −64°C structure, and 11.6% for the 35°C structure. Shifts in atomic coordinates, and changes in thermal oscillations, are reported for both transition points.

* Research supported by the U. S. Atomic Energy Commission and the Signal Corps Engineering Laboratories.
[1] Frazer, McKeown, and Pepinsky, Phys. Rev. **94**, 1435 (1954).
[2] C. A. Beevers and W. Hughes, Proc. Roy. Soc. (London) **177**, 251 (1941).

P3. Theory of Transition in KDP. YUTAKA TAKAGI,* *University of Chicago.*—Slater's celebrated model[1] of the transition in KDP, that is, the ordering of hydrogens below its Curie temperature at 123°K, has recently been confirmed by Bacon and Pease. However, this was not all that happened since the presence of ionic displacements of considerable magnitude has also been revealed by detailed x-ray analysis by Frazer and Pepinsky. It seems that the latter but not the former is the main origin of the ferroelectric polarization of KDP. The ionic shifts really occur in the C-direction, along which a typical hysteresis loop can be observed, whereas the movements of hydrogens in the process of ordering are confined to be nearly perpendicular to this polarization axis. The statistical mechanical treatment has been reformulated in order to take into account the effect of ionic shifts as well as the local field. The results are: (1) the transition point changes according to variation of electronic polarizabilities of ions as well as ionic polarizability of the crystal; and (2) the spontaneous polarization can decay in various manners according to the choice of parameters. For example, the polarization decays in a two-step manner if the anisotropy energy originally introduced by Slater were to be negligible.

* On leave from Tokyo Institute of Technology, Tokyo, Japan.
[1] J. C. Slater, J. Chem. Phys. **9**, 16 (1941).

P4. Piezoelectric Effects in Tetragonal and Orthorhombic Barium-Titanate Single Crystals.* DON A. BERLINCOURT, HANS JAFFE, AND LEBO R. SHIOZAWA, *Clevite Research Center.*—New measurements of piezoelectric and elastic constants of barium-titanate crystals by resonance methods from 25°C to −40°C show higher piezoelectric coupling in the tetragonal state than previously reported. Measurements were made on bars elongated in the tetragonal (100) and (110) direction as well as on square plates and disks; the tetragonal (001) axis was oriented in the thickness direction by cooling through the Curie point under 600 volt/mm dc. On cooling from the tetragonal to the orthorhombic state excitation of the longitudinal mode of the (100) bars is much reduced; instead strong coupling to a width controlled mode sets in. In (110) bars, increased coupling (up to 75%) to the longitudinal mode is observed. Square plates and disks show a sharp drop in resonant frequency at the tetragonal-orthorhombic transition such that their frequency constant becomes lower than that of (110) bars. These observations indicate that orthorhombic barium-titanate exhibits a substantial face shear piezoelectric effect, d_{36}, related to the pseudo-cubic axes. Presence of such a shear would require that the polar axis in this state is the (001) axis common to the tetragonal and orthorhombic symmetries. This conclusion is in conflict with earlier interpretations of optical observations and points to the need for structure studies of the orthorhombic state.

* Supported in part by the Acoustics Branch, Office of Naval Research.

P5. Crystal Structures of Two Tetragonal Pseudo-Spinels. E. PRINCE,* *Bell Telephone Laboratories.*—Copper ferrite and copper chromite have structures which are tetragonal distortions of the spinel structure. These structures have been determined by neutron diffraction. Copper ferrite is an inverted spinel, the c/a ratio is greater than 1, and the distortion elongates the octahedral sites, leaving the tetrahedral sites undistorted. Copper chromite is a normal spinel, the c/a ratio is less than 1, and the oxygen tetrahedra are flattened. The chromium ions are displaced from their ideal positions, so that the center of symmetry is removed. The magnetic structure of copper ferrite is consistent with the Néel model. That of copper chromite is more complex.

* Guest scientist at Brookhaven National Laboratory.

P6. Composition Dependence of the Magnetocrystalline Anisotropy of Magnesium-Iron Ferrites. V. J. FOLEN AND G. T. RADO, *Naval Research Laboratory.*—Several spherical monocrystals[1] in the system[2] $(MgO)_{1-x}(FeO)_xFe_2O_3$ were used to measure the first-order anisotropy constant K (by torque methods) and the saturation magnetization (by force methods) at temperatures between 26 and −196°C. The spheres were oriented by x-rays, and usually three orthogonal (100) planes were used to determine K accurately. We find that at room temperature the linear relation $K=-85000x-25000$ ergs/cc approximately represents the data for $0.2\leq x\leq 1$, and possibly for smaller x. The deviations are primarily due to the variations of cation distribution discussed in the following abstract (Rado and Folen). To investigate chemical effects, the ferrous ion content (x) of three samples was decreased by an oxidation resulting from a five-day heating at 620°C in air. $|K|$ was found to decrease in each case, the change becoming larger for compounds having larger initial magnetite content. The newly determined x for one such sample substantiated the linear K *versus* x relation. The large magnitude of the extrapolated K obtained for $x=0$ is interesting because a free Fe^{+++} is in an S ground state.

[1] Five compositions supplied by the Rutgers Ceramic Laboratory, and one by the Linde Air Products Company.
[2] Chemical analyses were kindly performed by Dean I. Walter of the National Research Laboratory.

P7. Sublattice Effects in the Magnetocrystalline Anisotropy of Magnesium-Iron Ferrites. G. T. RADO AND V. J. FOLEN, *Naval Research Laboratory.*—Using the $(MgO)_{1-x}(FeO)_xFe_2O_3$ monocrystals of the preceding abstract (Folen and Rado), we show that the nature of the cation distribution among the tetrahedral (A) and octrahedral (B) interstices has a small but significant influence on the first-order anisotropy constant K. If the absolute saturation magnetization (expressed by the number n of Bohr magnetons/molecule) is decreased by a suitable heat treatment in which a helium atmosphere insures a fixed x, then the room temperature value of $|K|$ is found to increase. For example, measurements on three orthogonal (100) planes of a sphere having $x=0.255$ show that a decrease of n from 2.44 to 1.75 causes a change of K from −44100 to −48700 ergs/cc. The few data obtained so far are correlated at room temperature by our tentative formula, $K=K_B{}^{++}x+K_A{}^{+++}(10-n+4x)/10+K_B{}^{+++}(10+n-4x)/10$, where $K_B{}^{++}$, $K_A{}^{+++}$, $K_B{}^{+++}$ denote the contributions to K resulting from one Fe^{++}, Fe^{+++}, Fe^{+++} per molecule being on B, A, and B interstices, respectively. Lastly, our evidence that $|K|/M_s$ is rather large, and depends more strongly on temperature than M_s, is shown to support the interpretation[1] of the two natural resonances observed in sintered Mg–Fe ferrites.

[1] G. T. Rado, Revs. Modern Phys. **25**, 81 (1953).

P8. Magnetostriction and Magnetic Anisotropy Constant of MnBi. H. J. WILLAMS, R. C. SHERWOOD, AND O. L. BOOTHBY *Bell Telephone Laboratories.*—Magnetostriction of oriented and nonoriented polycrystalline MnBi has been measured. A value of -250×10^{-6} was measured parallel to a field of 22 000 oersteds oriented perpendicular to the c-axis of the aligned hexagonal crystallites. This field magnetized the specimen to only slightly more than half of saturation. By plotting the magnetostriction as a function of $(B-H)^2$ and extrapolating to saturation, a value of -800×10^{-6} was obtained. This saturation value, to be considered tentative, is higher than any

published value for other materials. A value of 9.1×10^6 ergs per cm^3 was obtained for the magnetic anisotropy constant K_1, in agreement with Guillaud's value.[1]

[1] Thesis, Strasbourg (1943).

P9. Determination of the Second Coefficient of Ferromagnetic Anisotropy, K_2, of Cubic Crystals. H. SATO AND B. S. CHANDRASEKHAR, *Westinghouse Research Laboratories.*—Since the magnetic anisotropy constants K_2 of cubic ferromagnetic substances so far obtained are completely untrustworthy, we attempted newly to redetermine the K_2 values for iron and nickel. Magnetic torque measurements were made in the (111) plane of single crystals to eliminate the K_1-contribution as completely as possible. The data were analyzed with the aid of theoretical considerations which permitted the singling out of the K_2-contribution. The results are quite different from the values tentatively obtained by earlier investigators. The values of K_2 for iron is almost one order of magnitude smaller than that of K_1 both at room and liquid nitrogen temperatures. In the case of nickel, K_2 is the same order of magnitude as K_1, and its temperature dependence is even larger than that of K_1.

P10. Antiferromagnetic Spin Correlation in CoO.† A. W. MCREYNOLDS AND TORMOD RISTE,* *Brookhaven National Laboratory.*—The antiferromagnetic structure of CoO below a Néel point of about 15°C leads to a strong neutron diffraction superlattice peak from the (111) planes.[1] The intensity and shape of this peak from a CoO single crystal have been studied as a function of temperature in the region 0–50°C and of position in reciprocal space near the (111) point of the magnetic cell. A diffuse peak, which has maximum intensity at the Néel point, persists with decreasing intensity and increasing width at higher temperature. This represents a short range correlation between spins after disappearance of the long-range antiferromagnetic order. The correlation function $\gamma(r)$ between pairs of atomic spins at distance r has been determined for several temperatures and is found approximately isotropic. $\gamma(r)$ is of appreciable magnitude for only a few interatomic distances except near the Néel point where it extends to larger range.

† Under the auspices of the U. S. Atomic Energy Commission.
* On leave from JENER, Kjeller, Norway.
[1] Shull, Strauser, and Wollan, Phys. Rev. **83**, 333 (1951).

P11. Some Properties of the Coercive Force in Soft Magnetic Materials. D. S. RODBELL AND C. P. BEAN, *General Electric Research Laboratory.*—The coercive force is the value of the magnetic field amplitude when the net magnetization in the direction of the field is zero and has a zero rate of change. An equivalent definition of the coercive force is contained in the expression for the average instantaneous domain wall velocity; $v=k(H-H_c)$, in which k depends upon motional energy losses and H is the applied magnetic field; H_c is the coercive force. We have used this latter definition to measure the coercive force in specimens of magnetically annealed 65 Permalloy (65% Ni-Fe) tapes and a 3.25% SiFe picture frame single crystal for both low- and high-field domain configurations. The coercive force measured in this way for low applied fields is the same as that determined by other techniques. For the high-field determination, with domain walls unattached to the specimen surfaces, the coercive force is for our samples, less than half the low-field coercive force. We call the values determined at high fields the "internal coercive force" and believe this value to be characteristic of the bulk material. The low-field coercive force includes both the "internal coercive force" and a component due to surface imperfections. These experiments support an explanation of the dependence of coercive force upon specimen thickness previously postulated.

FRIDAY AFTERNOON AT 2:00

Mellon Institute Conference Room

(A. J. ALLEN presiding)

General Physics

Q1. General Theory of Optically Compensated Varifocal Systems. LEONARD BERGSTEIN, *Columbia University* (introduced by L. Motz).—A general theory of optically compensated varifocal systems will be disclosed in this paper. In accordance with this theory n alternately stationary and movable lens components can be arranged to produce an optical system which will have an over-all focal length variable continuously between two predetermined values upon a linear displacement of the movable components from their reference position to a maximum value and thereby n predetermined positions will stand out for which the deviation of the image plane from a predetermined location is zero; at intermediate positions this deviation is relatively small. The larger the value of n the closer the spacing of the points of full compensation and the smaller the image deviation becomes at intermediate points. As a result the maxima of the image deviation approach zero as the number of components is increased. The number n of components will be determined by the desired ratio of maximum to minimum over-all focal length and the specified limit for the maxima of the image deviation. These two requirements also lead to $(2n-2)$ equation which can be readily solved for the $(2n-2)$ Gaussian parameters of the varifocal system.

Q2. Statistical Mechanics of Two-Dimensional Soap Bubbles. RYOICHI KIKUCHI,* *University of Chicago.*—When soap bubbles are formed in a narrow space between two glass plates, bubbles take approximately polygonal shapes with varying number of sides, $n(\geq 3)$. Probability distribution of polygons with n-sides was calculated based on a model and using a technique of statistical mechanics developed by the author.[1] The result fits the experimental observations qualitatively.

* Now at Armour Research Foundation, Chicago, Illinois.
[1] R. Kikuchi, Phys. Rev. **81**, 988 (1951).

Q3. Description of a Uniform Stark Field Microwave Absorption Cell. S. A. MARSHALL AND J. WEBER, *U. S. Naval Ordnance Laboratory.*—A microwave Stark cell which develops electric fields having a uniformity conservatively estimated at 1 part in 10 000 has been designed and constructed. The configuration of the cell is essentially that of a plane parallel transmission line with an absorption path of four feet. The cell plates are optically ground and polished glass upon which a conductive coating has been deposited. Microwave power is fed to the cell by means of electromagnetic horns. The first work undertaken with this instrument has

been the investigation of the Stark effect of OCS (carbonyl sulfide). Although the work is still in progress, it is felt that the dipole moment of this molecule in its ground vibrational state will be determined to within 1 part in 1000. Because of the quadratic field dependence of polarizability energy, there exists a fair chance of getting estimates of molecular polarizabilities in linear molecules. Preliminary work on OCS indicates $|\alpha_{xx}-\alpha_{zz}|$ to be roughly 10^{-24} cm^3. Fourth-order Stark perturbation has been detected in the rotational energy level splitting of OCS and its effect is in substantial agreement with theory.

Q4. Evidence for an Electron-Photon Electron-Multiplication Process in High-Gradient Acceleration Tubes. C. M. TURNER, *Brookhaven National Laboratory.*—Following initial observations of the ionization loading effect in electrostatic accelerators,[1] observations were extended to a 7-foot long section of the six-inch aperture stainless-steel electrode tube built for the Cosmotron injector, to determine the effectiveness of anode bremsstrahlung suppression in reducing the excessive loading which rendered it useless.[2] Results showed that (1) its behavior was not appreciably improved, (2) the bremsstrahlung responsible for its excessive loading were originating predominantly on the tube electrodes rather than at the anode, and (3) the bremsstrahlung intensity increased exponentially with distance from cathode-to-anode end. Free electrons accelerated by the electric field produce bremsstrahlung photons upon colliding with tube electrodes. These photons can liberate further compton and photoelectrons from subsequent electrodes, etc. Analysis indicates that both photon production by this mechanism and associated ionization loading should vary approximately as the sixth power of tube aperture and gradient, and exponentially with atomic number of electrode material.

[1] C. M. Turner, Phys. Rev. **95**, 599 (1954).
[2] C. M. Turner, Phys. Rev. **81**, 305 (1951).

Q5. Proton Stopping Cross Sections of Gases.* S. MILANI,† JOHN N. COOPER, AND J. C. HARRIS, *Ohio State University.*—The stopping cross sections of nitrogen, xenon, air, water vapor, carbon dioxide, and benzene have been measured for protons with energies from 400 to 1000 kev. The protons entered the gas chamber through a foil prepared by evaporating silver onto a Formvar film. In the case of air a thin coating of LiF was evaporated over the silver to prevent oxidation. The proton energy scale was calibrated by use of the proton-capture resonances in lithium and fluorine. The loss in proton energy in traversing the gas was measured by observing the displacement of these resonances. The curves for all the gases join smoothly with curves reported by Dunbar, Reynolds, Wenzel, and Whaling[1] for proton energies under 600 kev. The stopping cross sections of the gaseous compounds are in agreement with Bragg's law within experimental error.

* Supported in part by the U. S. Atomic Energy Commission through a contract with the Ohio State University Research Foundation.
† Now at General Electric Company, Schenectady, New York.
[1] Dunbar, Reynolds, Wenzel, and Whaling, Phys. Rev. **92**, 742 (1953).

Q6. Range-Energy Relations for Law Energy Alpha Particles.* G. W. GOBELI† AND E. BLEULER, *Purdue University.*—The range-energy relations in Ge, Si, InSb, Al, Cu, Ag, and Au were determined by measuring the air equivalents of thin foils of the materials for incident alpha energies between 0.7 Mev and 4.4 Mev which were obtained at the sample position by using air as a variable absorber. A CsI(Tl) crystal was used as an energy sensitive detector and the pulse-height distributions of the incident and transmitted alpha particles were observed with a 20-channel pulse-height analyzer. The ranges in microns in Si, Ge, and InSb are $R_{Si}=2.08E^{1.46}+2.12$, $R_{Ge}=2.24E^{1.32}+1.12$, and $R_{InSb}=2.46E^{1.30}+0.85$, respectively ($E$ in Mev). The standard errors for calculations involving range differences for the energy region above 0.5 Mev are 3.3%, 3.5%, and 7.4%, respectively. The additive constants are somewhat uncertain because of the lack of accurate information below 0.5 Mev. The ranges for the semiconductors interpolate smoothly between those of the metals, which are in good agreement with available data.

* Work supported by a U. S. Signal Corps Contract.
† IBM research fellow.

Q7. Angular Distribution of Protons from the $B^{10}(He^3,p)C^{12}$ Reaction. R. L. JOHNSTON AND H. D. HOLMGREN, *Naval Research Laboratory.*—A thin B^{10} target was bombarded by 2-Mev He^3 particles from a NRL Van de Graaff generator, and the angular distributions of the protons leaving C^{12} in the ground state and first-excited state were observed. The protons were recorded in Ilford 200-micron c-2 emulsions placed at 10-degree intervals from 5 to 155 degrees. The two proton groups were identified by measuring the range spectrum in the emulsions. The yield of the ground-state protons tends to rise with increasing angle. The yield of the first-excited group is fairly flat from 5 to 65 degrees and then decreases to about 60% of the maximum value at 145 degrees. The yield of ground-state protons is approximately 10% of the yield of the first-excited state protons.

Q8. Gamma Rays Emitted by Rh^{102}. J. D. KURBATOV, KAZUO HISATAKE, AND JAMES T. JONES,* *Ohio State University.*—Carrier free Rh^{102} was separated from activated ruthenium. After a sufficient period of time was allowed for disintegration of the shorter lifed isotopes of rhodium the decay of Rh^{102} into Ru^{102}, and Pd^{102}, stable isobars, was studied. In the investigation of the complicated scheme of disintegration of Rh^{102}, first study was of the energy and intensity of gamma rays and their coincidences. The energies of the gamma rays in kev resulting from the decay of the energy level, $T_{\frac{1}{2}}=210$ days of Rh^{102} in order of their intensities are as follows: 479 ± 5, intensity 1; 1090 ± 20, ~0.2; 630 ± 20, ~0.2; 190 ± 5, ~0.07; 1820 ± 20, ~0.06; 125 ± 5, ~0.04; 770 ± 30 ~0.02; 1470 ± 20, <0.01. The energies of low-intensity gamma rays, observed in Rh^{102}, are less certain mainly because of scattering. Their supplementary contribution of the main scheme of disintegration will be evaluated.

* Major, U. S. Air Force, at present on tour of duty at the Ohio State State University.

Q9. Decay of W^{185}. T. C. SEBASTIAN AND A. H. WEBER, *Saint Louis University.*—There is some uncertainty about the decay of this isotope, some workers[1] characterizing it as a pure β emitter with a single energy level at 435 kev from which it decays to the ground state, while others[2] have observed conversion lines corresponding to a γ ray of 134-kev energy and have attributed two levels[3] (634 and 134 kev) to it. The present investigation with a NaI(Tl) scintillation spectrometer, showed the existence of a highly converted γ ray at about 132 kev when the K x-ray has been suppressed with copper absorbers. Measurements on the beta spectrum with a thin lens spectrometer however, showed only very weak conversion lines corresponding to this γ ray. The results obtained may be interpreted by a new decay scheme having energy levels of 435 and 303 kev above the ground state with the dominate transition occuring from the 435-kev level to the ground state, while a low-intensity γ ray from the 435- to the 303-kev level and a 132-kev γ ray in cascade, leading to the ground state, accounts for the observed conversion lines and γ ray.

[1] Lazar, Moffat, and Langer, Phys. Rev. **91**, 498 (A) (1953).
[2] Cork, Keller, and Stoddard, Phys. Rev. **76**, 575 (1949).
[3] Goldhaber and Sunyar, Phys. Rev. **83**, 906 (1951).

Q10. Slowing Down of Neutrons. M. LEICHTER, *Lockheed Aircraft Coproration.*—In reactor calculations it is customary to approximate the average number of collisions necessary to

reduce the neutron energy from an initial value E_0 to a final value E by $\bar{n}=(1/\xi)\ln(E_0/E)$ where ξ is the average logarithmic decrement per collision.[1] The average number can also be computed from $\bar{n}=\Sigma P_E(n)/\Sigma P_E(n)$ where $P_E(n)$ is the probability density of the neutron having energy E after n-collisions. Using the expressions for $P_E(n)$ as given by Condon and Breit[2] the result, after some manipulation, is $\bar{n}=N/D$ where

$$N=\sum_{k=0}^{R}(-1)^k/k!\{\beta_k{}^{k-1}[\beta_k+(k+\beta_k)^2]\}\exp\beta_k,$$

$$D=\sum_{k=0}^{R}(-1)^k/k!\beta_k{}^{k-1}[k+\beta_k]\}\exp\beta_k,$$

where $\beta_k=\nu(c-k)$, $\nu=-\ln\alpha/(1-\alpha)$, $\alpha=(A-1)^2/(A+1)^2$, A = mass of scattering nucleus/mass of neutron, $c=(\ln E_0/E)/-\ln\alpha$, R = greatest integer less than c. Numerical values will be given.

[1] Glasstone and Edlund, *The Elements of Nuclear Reactor Theory.*
[2] E. U. Condon and G. Breit, Phys. Rev. **49**, 229 (1935).

Q11. Nuclear Diffuse Edge Approximation. D. C. PEASLEE, *Purdue University.*—For exploratory diffuse edge calculations, some numerical simplification results from replacing the diffuse edge by an effective sharp edge, whose position and complex reflection and transmission coefficients are estimated by WKB-type methods from the actual diffuse edge. The most direct application is to low-energy neutron measurements: in this approximation the $\langle\Gamma_n/D\rangle$ and $\langle a-R\rangle$ curves are simply multiplied by a factor $|T/T_0|^2$, the ratio (in the zero-energy limit) of transmission coefficients for the diffuse and sharp edges. Comparison with the measured $\langle\Gamma_n/D\rangle$ maximum at $A\sim53$ and minimum at $A\sim100$ indicates $|T/T_0|^2\approx2$, $\rho\approx0.04$; the scattering lengths agree with this value but do not themselves provide a reliable estimate of $|T/T_0|^2$. The observed $\langle\Gamma_n/D\rangle$ maximum at $A\sim160$ is now much too low: its height and breadth are more suggestive of $\rho\sim0.1$. The value $|T/T_0|^2\approx2$ is in agreement with diffuse edges inferred from analysis of elastic proton scattering.[1]

[1] D. Saxon *et al.*, Michigan Conference, June, 1954.

Q12. Photonuclear Process in Spheroidal Nuclei. M. DANOS, *National Bureau of Standards.*—Generalizing the hydrodynamical model of the photonuclear process[1] to the case of a deformed nucleus one finds that the eignevalues of the dipole oscillation are split. This results in (1) a larger effective width of the resonance and (2) an assymmetry in the resonance shape depending on the sign of the quadrupole moment; the center of gravity of the absorption remains essentially unchanged. The ratio of the split resonance frequencies is to a very good approximation equal to the ratio of the intrinsic axes of the ellipsoid. In a nucleus with a positive quadrupole moment, which has two short and one long axis, the absorption cross section will consist of the superposition of a peak shifted to a lower frequency and a peak twice as high shifted roughly half as far to a higher frequency. Conversely for a negative quadrupole moment. The ground state deformations can be used because there is no coupling between the internal dipole motion and surface oscillations even taking into account compressibility of nuclear matter.[2]

[1] M. Goldhaber and E. Teller, Phys. Rev. **74**, 1048 (1948); J. H. D. Jensen and P. Jensen, Z. Naturforsch. **5a**, 343 (1950).
[2] J. M. Araujo, Nuovo cimento (9) **12**, 780 (1954).

Q13. Thorium Stars in Nuclear Emulsions. C. A. RANDALL, JR., AND L. J. GALLAHER, *Ohio University.*—Thorium stars in a 100μ NTA emulsion soaked in thorium nitrate have been measured with 970× magnification and the individual α particles identified by range measurements. Not all of the α particles in a star emanate from a common center. In these stars "gaps" are observed between the origins of one or more of the α particles emitted by Th^{228} and its progeny. Two features have been observed which suggest that the gaps are not due to simple diffusion. (1) The mean value of the gaps between the origin of a given α particle and the origin of its successor bears no simple relationship to the mean life of the emitter of the second α particle. (2) If it is diffusion, elementary considerations indicate that the probability of finding the "gap length" between r and $r+dr$ is $r/D\tau\exp(r/D\tau)$ where τ is the mean life of the isotope diffusing and D is the coefficient of diffusion. Preliminary data indicate that there are many more zero length gaps than can be accounted for on this basis.

FRIDAY AFTERNOON AT 2:00

Mellon Institute Social Room

(R. BRAY presiding)

Irradiation Effects on Nonmetals

R1. Electron Bombardment Induced Noise in *p-n* Junctions. W. H. FONGER, J. J. LOFERSKI, AND P. RAPPAPORT, *RCA.*—When high-energy particles bombard a *p-n* junction, ionization in the semiconductor causes a multiplication of the primary current (I_B). The primary current contains shot noise and this noise is multiplied in the semiconductor. By analogy to the behavior of photomultipliers, the mean square noise current in the multiplied current is given by

$$\langle i_n{}^2\rangle_{Av}=2eI_B\Delta f(\bar{m}^2+\langle\delta m^2\rangle_{Av})$$

where $\bar{m}$ is the average multiplication and $\langle\delta m^2\rangle_{Av}$ is the mean square deviation in m. This equation has been confirmed by us for Ge and Si *p-n* junctions bombarded by a 0.050-curie Sr90–Y90 beta source. If it is assumed that $\langle\delta m^2\rangle_{Av}\ll\bar{m}^2$, it is found that $\bar{m}\sim1.5\times10^5$ in agreement with other measurements.[1] The noise spectrum was white up to about 10^5 cps which limit is imposed by transit time for carriers in the semiconductor. A simultaneous measurement of the multiplied current ($I_s=\bar{m}I_B$) determines I_B and $\bar{m}$ separately. Furthermore since $\bar{m}=\bar{V}_B/\bar{w}$ where $\bar{V}_B$ is the average energy of the primary particles and $\bar{w}$ is the average energy expended in generating a hole-electron pair, $\bar{V}_B$ can also be determined. Thus the phenomenon can be used to determine the characteristics of the ionizing radiation.

[1] P. Rappaport, Phys. Rev. **93**, 246 (1954).

R2. Effects of Gamma Radiation on Germanium. J. W. CLELAND, J. H. CRAWFORD, JR., AND D. K. HOLMES, *Oak Ridge National Laboratory.*—High-purity *n*- and *p*-type samples of Ge have been exposed to γ rays from a 900-curie Co^{60} source. The extrinsic electron concentration of *n*-type material decreases at a rate only $\sim10^{-3}$ of that for fast neutron irradiation. Two electron trapping levels which are apparently

identical to those produced by fast neutrons have been observed. Extended exposure converts *n*-type material to *p*-type indicating the presence of an acceptor level at ~0.26 ev above the valence band. This energy is somewhat larger than that found in fast neutron irradiated material. Interstitial clustering and nonuniform defect distribution are believed to lower the energy levels produced by fast neutrons; hence energetic photons apparently produce randomly distributed defects throughout the volume of the specimen. Exposure of *p*-type material causes a decrease in extrinsic hole concentration with a removal rate much less than that for *n*-type Ge. The cross section for atomic displacements obtained from these results is $\sim 4 \times 10^{-26}$ cm². This value is in reasonable agreement with the calculated cross section expected for the Compton and photoelectrons produced by Co^{60} γ-ray absorption in Ge.

R3. Kinetics of Radiation Induced Coloring.* PAUL W. LEVY, *Brookhaven National Laboratory.*—When various substances, e.g., Al_2O_3, crystalline quartz, and fused silica, are exposed to gamma-ray or reactor radiations optical absorption bands are formed. The growth curves of these bands as a function of dose or time can be divided into different classes, e.g., linear growth plus a saturating exponential. Each of these growth curves can be "explained" by simple processes, e.g., if vacancies are produced at a constant rate and if a given fraction of the uncolored vacancies is colored per unit time a "nucleation and growth" type curve occurs. Some absorption bands grow to a definite maximum and then remain constant or decrease in any of several ways. Again, "explanations" can be given, e.g., a process involving production of vacancies and interstitials will have maximum coloration controlled by the rate of recombination of interstitials and vacancies and/or color centers. In Al_2O_3 the growth of the reactor induced bands at 2040 A can be divided into a linear part and a saturating exponential. In crystals from the same batch the maximum density of the exponential part is independent of flux while the slope of the linear part is proportional to the flux.

* Under the auspices of the U. S. Atomic Energy Commission.

R4. Structure Sensitivity of the X-Ray Coloration of NaCl Crystals.* R. B. GORDON† AND A. S. NOWICK, *Yale University.*—Crystals of NaCl (Harshaw) were irradiated at room temperature with unfiltered (40 kv) x-rays, and observations of *F*-band growth were made as a function of depth below the irradiated surface and prior treatment of the specimens. The results lead to the conclusion that two mechanisms of coloring operate in these crystals: (1) "Rapid-type" coloring, which ceases at a saturation density of 6×10^{16} *F*-centers/cm³, appears to result from the generation of *F*-centers from vacancies already present in the unirradiated crystal. This type of coloring proceeds at essentially the same rate for deformed as for carefully annealed crystals; however, as-received crystals, and those recovered at low temperatures after deformation show a lower coloring rate. These observations suggest that the effects of deformation and heat treatment may be related to the state of dispersion of impurities. (2) "Slow-type" coloring takes place at a constant rate until *F*-centers in excess of 10^{18}/cm³ are formed. For moderate irradiation, it is detectable only in a thin layer near the surface of incidence of the x-rays. Presumably, this type of coloring results from the generation of *F*-centers at dislocations.

* Work supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
† Now at Columbia University.

R5. Effect of Dislocations on γ-Ray Coloration of NaCl Crystals.* A. S. NOWICK, *Yale University.*—The rate of growth of the *F*-band was observed for various NaCl crystals colored uniformly in a Co^{60} gamma source (191 000 r/hr). Evidence was again found for the existence of two types of coloring, consistent with the results of the previous paper. For irradiations up to 1 hr, primarily "rapid-type" coloring occurs; coloring rates for deformed and annealed crystals are substantially the same. For 20- to 50-hour irradiations striking increases are observed in the rate of growth of the *F*-band of deformed crystals as against that for annealed crystals. For example, a specimen deformed 4% in compression colors about four times faster than an annealed crystal in this range of irradiation times. This sensitivity of colorability in the later stages to dislocation density appears to support the suggestion of the previous paper that only the slow-type coloring results from the generation of *F*-centers at dislocations. The behavior upon reirradiation, of specimens which had been partially thermally bleached, also supports this contention.

* Experiments conducted at the Brookhaven National Laboratory.

R6. Gamma-Ray Coloration of Sodium Chloride. W. DALE COMPTON, *U. S. Naval Research Laboratory.*—Coloration of sodium chloride by Co^{60} gamma rays was carried out at room temperature on natural crystals and on synthetic crystals grown in this laboratory and procured from the Harshaw Chemical Company. As other investigators have reported, the coloration rate was less for the natural than for the synthetic crystals. For doses below 100 megaroentgen only the *F*- and *M*-bands appeared. At greater doses a very prominent band appeared at 580 mμ in the synthetic crystals. This band was barely perceptible in the gamma irradiated natural crystals, but it developed rapidly when these crystals were illuminated with *F*-band light. Illumination with light of wavelength greater than 640 mμ did not develop it. Measurements indicate that this band is not appreciably sharper at liquid nitrogen temperature than at room temperature and that the peak shifts less than 10 mμ from its room-temperature position. This suggests that this band is the *R'*-band associated with the colloidal metal. A strong band is developed at 840 mμ by illumination with *F*-band light and a weak band appears at about 930 mμ after high gamma irradiation.

R7. Fast Neutron damage in Quartz and Vitreous Silica.* W. PRIMAK, *Argonne National Laboratory.*—On irradiation in nuclear reactors, vitreous silica exhibited a negative dilatation which reached a maximum about 2.7% at a damaging *nvt* about 4×10^{19} and then declined gradually by several tenths percent. Quartz showed several stages of positive dilatation: (1) an initial period of slow dilatation with a tendency to saturate (up to about 2×10^{19} *nvt*), (2) a middle period (up to about 1.5×10^{20} *nvt*) of much more rapid dilatation, and (3) a final period of slow dilatation with saturation at the density of irradiated vitreous silica. (Quantitatively the present results differ somewhat from Wittels and Sherrill's.) On heating irradiated quartz it was found that (1) a sample from the initial period contracted toward the original density, (2) a sample from the middle period showed a further dilatation at lower temperatures followed by a contraction at higher temperatures, and (3) a sample from late in the final period showed a further dilatation and much the same annealing behavior as irradiated vitreous silica. Thus quartz from the middle period seems to consist of two phases, i.e., damaged quartz and irradiated vitreous silica. The results support the hypothesis of the importance of thermal spikes in the middle and final periods and, by implication, in the damaging of vitreous silica.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

R8. Neutron Specify of a Color Center in Certain Specimens of Fused Silica. ALVIN J. COHEN, *Mellon Institute.*—The 214 mμ color center is known to be produced in fused silica by all types of high-energy radiation. That a subsidiary color center at 242 mμ is also produced by pile irradiation has been reported earlier.[1] It has now been established in this laboratory that this subsidiary color center is developed in Hereaus Homogenized Ultrasil fused silica by pile irradiation alone

(irradiated, courtesy of G. J. Dienes and P. W. Levy, Brookhaven National Laboratory) and not by x-ray (50 PKV, 20 ma), electron beam or even proton bombardment at 400 Mev (bombardment, courtesy of R. Smoluchowski and E. Pearlstein, Carnegie Institute of Technology). One lot of Corning purified fused silica also develops this peak on pile irradiation and not upon prolonged x-ray treatment while a different lot develops the subsidiary peak under all conditions studied. This 242 mμ center is not to be confused with a "chemical" peak present in most fused silica at the same wavelength. Speculations concerning the nature of these entirely different bands at 242 mμ will be presented.

[1] P. W. Levy, J. Chem. Phys. **23**, 764 (1955).

R9. Effect of Displaced Atoms on the Oxidation of Graphite.* W. L. KOSIBA AND G. J. DIENES, *Brookhaven National Laboratory*.—The purpose of this investigation is to determine the influence of lattice defects, produced by exposure to neutrons in a reactor, on a gas-solid reaction. The graphite-oxygen reaction on irradiated and unirradiated samples has been studied over the 300–400°C temperature range. The irradiated samples were exposed to about 4×10^{20} neutrons/cm² in the reactor prior to oxidation. This exposure, which produces about 2% displaced atoms at room temperature, increased the oxidation rate relative to an unirradiated sample by about a factor of seven. The oxidation rate of untreated samples in the presence of gamma rays alone (210 000 rep/hr) was hardly altered. The reaction rate of a sample previously irradiated in the reactor and oxidized in the presence of gamma rays was higher by an additional factor of 2, i.e., a factor of 14 relative to unirradiated specimens. It is concluded that displaced atoms exert a large influence on the rate of this heterogeneous gas-solid reaction. When, in addition, ionizing radiation is present during the reaction the rate is further increased, probably due to the ionization of oxygen molecules.

* Under contract with the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Stephen Foster Social Room

(A. W. LAWSON presiding)

Various Topics in Metal Physics

S1. Thermal Diffusivity of Armco Iron at Elevated Temperatures.* P. H. SIDLES, *Iowa State College*.—The thermal diffusivity of Armco iron has been measured from room temperature to 1000°C by means of a dynamic technique which has been described previously.[1] With this technique, thermal diffusivity measurements accurate to ±2% are possible at essentially a point in temperature, thus permitting an investigation of the thermal behavior of a metal near phase transformations and Curie temperatures. The thermal diffusivity of Armco iron exhibits a minimum at the Curie point and a discontinuous increase at the α–γ transformation at 910°C. This behavior is, as might be expected, approximately equal in magnitude but opposite in direction to that reported for the specific heat of iron. Hence the thermal conductivity changes slope at the Curie point and passes smoothly through the phase transformation. The thermal conductivity of Armco iron calculated from diffusivity, specific heat, and density data will be discussed.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
[1] P. H. Sidles and G. C. Danielson, J. Appl. Phys. **25**, 58 (1954).

S2. Adsorption of Rb^+ on Tungsten.* F. HUGHES AND H. LEVINSTEIN, *Syracuse University*.—The mean adsorption lifetime, τ, of Rb^+ on tungsten has been measured using an interrupted molecular beam technique. Maximum Rb concentration was about 10^{10}/cm² ($\theta\cong10^{-4}$). The data may be represented by the equation $\tau=\tau_0\exp(+Q/kT)$ in the region $1100<T<1300$°K. The constant τ_0 is determined by the shape of the surface potential barrier whose height is Q. For surface ionization processes, Q is almost totally due to the ionic image potential and should be relatively insensitive to the environment near the surface. Measurements made on contaminated surfaces show τ_0 to be very sensitive to surface conditions. Thus, in characterizing "chemical" adsorption processes, the adsorption time may be a more significant parameter than the adsorption energy. Indirect information about surface-contaminant interactions which results from the use of this technique will be discussed.

* Supported by the Office of Ordnance Research.

S3. Extended Method of Reaction Rates for Solids.* PETER GIBBS, *University of Utah*.—Reaction rates are often analyzed assuming near-equilibrium and a series of equal energy barriers. When creep of a weighted wire is thus examined, it is found that different barrier parameters must be taken at each instant. Solids differ statistically from gases and solutions because the whole solid is properly a single system, which may be altered slightly by each barrier passage. Transitions over second lowest barriers are not automatically neglectable, because of the large possible effects of small imperfection concentrations. A more general problem of reactions on an energy hypersurface has been formulated, where transitions may be made "forward" over the lowest barriers, or "sideward" over higher barriers. Barrier parameters are functions of position on the hypersurface. Beginning from some standard state, the system is initially affected only by lowest barrier passages. Later, second lowest barrier passages make themselves felt in a way which may be distinguished by its temperature dependance, and so on. The problem has an exact solution for small displacements.

* Supported by the Office of Naval Research.

S4. Surface Energy of Jellium. R. J. MCINTYRE, *University of Virginia* (introduced by J. S. Plaskett).—Calculations of the surface energy of Jellium (a metal in which the positive ionic charge has been smeared out to form a uniform positive "jelly" with a sharp boundary) have been carried out following the models of Huntington[1] and Stratton.[2] Errors in the calculations of the above authors have been found and the corrected results yield a negative surface energy. This result is consistent with the negative surface energy obtained by the Thomas-Fermi method. By using the quantum-mechanical virial theorem, it can be shown that the self-consistent Hartree wave functions do indeed give a negative surface energy. It is suggested that the positive surface energy of metals arises not from the kinetic energy term in the expression for the total energy, but from the surface contribution of the exchange and correlation energies.

[1] H. B. Huntington, Phys. Rev. **81**, 1035 (1951).
[2] R. Stratton, Phil. Mag. **44**, 1236 (1953).

S5. Small Angle X-Ray Scattering from Cold-Worked Metals.* M. B. WEBB AND W. W. BEEMAN, *University of Wisconsin.*—Measurements have been made of the polarization of the diffusely scattered x-ray intensity at small angles from cold-worked metals (Ni, Cu, Al). For small deformations the polarization appears to be consistent with the double scattering mechanism proposed by Neynaber *et al.*[1] For larger deformations the polarization disappears and some other explanation of the small angle scattering is required. Two scatterings within the same coherent domain give a beam in the forward direction which, averaged over randomly oriented domains, is unpolarized. The possibility that the small angle scattering from heavily deformed metals arises from the physical broadenings of these reflections is discussed. In cases where the double scattering mechanism of Neynaber is applicable, the average tilt angle between adjacent subgrains can be calculated from the angular dependence of the scattering. The results are in general agreement with the measurements of Gay, Hirsch, and Kelly.[2]

* Supported by the Office of Scientific Research of the Air Research and Development Command and by an Eastman Kodak Fellowship.
[1] Neynaber, Brammer, and Beeman Phys. Rev. **99**, 615 (A) (1955).
[2] Gay, Hirsch, and Kelly, Acta Metallurgia **1**, 315 (1953).

S6. X-Ray Measurements of Cold Work in Beta Brass.* OTTO GUENTERT, *M. I. T.*—Cold-worked powder samples of beta brass have been made by filing at room temperature. Diffraction patterns were made with the Norelco diffractometer using CoKα and MoKα radiation. Three pairs of multiple orders were available for separating particle size and distortion broadening: 110–220, 200–400, and 211–422. Measurements were made on samples freshly filed, and also after annealing one year at room temperature. The particle size from the 110–220 pair increased from $L=270$ A to $L=350$ A and the root-mean-square strains decreased about 25% on standing one year at room temperature. The particle size values obtained from the 200–400 and 211–422 pairs are only about half the value obtained from the 110–220 pair. The possibility of explaining the particle size variation with direction in terms of twinning will be discussed.

* Research sponsored by the U. S. Atomic Energy Commission.

S7. Electron Microscope Studies on Deformed Aluminum Crystals.* T. S. NOGGLE† AND J. S. KOEHLER‡.—High-purity aluminum single crystals were strained in tension at 295°K, 78°K, and 4°K and the surface structures examined with an electron microscope. It was found that the slip-band structure normally observed at room temperature is modified in going to low temperatures such that only a fine-slip structure is observed on specimens strained at 4°K. Measurements on the surface structures show that the major effect of increased temperature is to reduce the average spacing of the slip lines, with only a small increase in the average shear per line. The stress-strain curves are raised and straightened in going to the lower temperatures, and a linear stress-strain behavior is observed at 4°K.

* This work sponsored by the Office of Naval Research.
† Now with the Solid State Division of Oak Ridge National Laboratory.
‡ University of Illinois.

S8. X-Ray Scattering and Thermal Vibrations in Aluminum.* C. B. WALKER, *University of Chicago.*—Measurements have been made of the scattering of monochromatic x-rays from single crystal aluminum at 300°K and at 5°K. The first-order temperature diffuse scattering determined from these measurements was analyzed by the method of Laval and James to obtain curves of frequency *vs* wave vector for the normal modes of vibration propagating along the three primary crystallographic directions. By interpreting these dispersion curves in terms of the Born theory of lattice vibrations, values were obtained for the nine interatomic force constants necessary to describe interactions with first, second, and third neighbors. The computer AVIDAC at the Argonne National Laboratory was used to solve the secular equation containing these force constants for the eigenfrequencies for 2791 wave vectors distributed uniformly through the minimum volume element of the first Brillouin zone. These frequencies were used to determine an approximate frequency distribution, and from this the specific heat *vs* temperature was calculated.

* Supported by the Office of Ordnance Research.

S9. Effect of Electron Density Fluctuations on the Annihilation of Positrons in Metals.* RICHARD A. FERRELL, *University of Maryland.*—The lifetime of a positron stopped in a metal is inversely proportional to the density of electrons at the position of the positron. This density is much greater than the average conduction electron density in the metal, because of the strong Coulomb attraction exerted by the positive charge of the positron. The annihilation rate is also augmented by a small additional effect which is independent of the positron charge. The Bohm-Pines canonical transformation, which approximately diagonalizes the Hamiltonian, adds to the annihilation operator a nonlocal part which excites plasma oscillations, as well as annihilating a positron-electron pair. The relative probability of exciting a plasma oscillation is approximately $(2\beta^5/5\pi)\cdot(k_0a_0)^3\cdot(E_0Ry^2/(\hbar\omega_p)^3)$, where β is the Bohm-Pines cut-off ratio, k_0 and E_0 the Fermi wave number and energy, ω_p the plasma frequency, and $\hbar$ and a_0 Planck's constant and the Bohr radius. Inserting free-electron expressions yields $0.0795\,\beta^5/\sqrt{r_s}$, or a few percent for sodium, where r_s, the radius of the unit sphere, is about four, and β is of the order of unity.

* Research supported by the Office of Naval Research.

S10. Absolute Values of Cu Mass Absorption Coefficients near the *K*-Edge.* WILFRED PALMER† AND HAROLD P. HANSON, *University of Texas.*—Measurements of the Cu mass absorption coefficients in pure copper, $CuSO_4\cdot 5H_2O$, and $CuBr_2$ have been made with a double spectrometer over the wavelength range from 1.52 to 1.21 K.X. units. The fine structure of the absorption curve in the immediate vicinity of the *K*-absorption edge at 1.377 K.X. units has been studied in each material. Differences between the edge structures of the cupric ion in aqueous solution[1] and in the crystalline compounds are treated as effects of the symmetry characteristics of the surroundings. The secondary structures out to 520 ev beyond the edge have also been determined for the three substances. Accurate absolute values of the mass absorption coefficients have been obtained by normalizing the curves to the values reported by Allen[2] for pure copper at wavelengths of 1.432 and 1.235 K.X. units. These points are sufficiently far from the edge to permit the use of the values for the pure element in normalizing the curves of the cupric compounds.

* Supported in part by the Robert A. Welch Foundation of Texas.
† Now at the University of Illinois.
[1] W. W. Beeman and J. A. Bearden, Phys. Rev. **61**, 455 (1942).
[2] S. J. M. Allen, Phys. Rev. **28**, 907 (1926).

S11. Nickel *K*-Absorption Edge in Supported Nickel Oxide Catalysts. R. O. KEELING, JR., *Gulf Research & Development Company.*—According to Selwood,[1] nickel oxide supported on γ alumina at low nickel concentrations contains nickel with an average oxidation state greater than +2, while nickel in nickel oxide on magnesia remains divalent at all concentrations. Since the position and structure of x-ray absorption edges should be sensitive to these differences in electronic structure, measurements of the Ni *K*-absorption edge were made on samples of nickel oxide on γ alumina containing 32.5, 12.5, 2.8, and 1.6% Ni (by weight) and on a sample of nickel oxide on magnesia containing 4.0% Ni. The edges in the alumina

samples with 32.5 and 12.5% Ni and in the magnesia sample are nearly identical to the edge in bulk nickel oxide. The edges in the alumina samples with 2.8 and 1.6% Ni occur about 1 ev below that of bulk nickel oxide, and, in addition, the absorption line on the high-energy side of the edge in these two samples is split into two peaks separated by approximately 2 ev. A possible explanation of the double peak in terms of electronic structure will be given.

[1] P. W. Selwood, *Advances in Catalysis* (Academic Press, Inc., New York, 1951), Vol. III, p. 62.

FRIDAY EVENING AT 7:00

Georgian Room, Webster Hall Hotel

(E. P. WIGNER presiding)

Banquet of the American Physical Society

Presentation of Oliver E. Buckley Solid-State Physics Prize

After-dinner speakers: P. D. Foote and H. Mark.

SATURDAY MORNING AT 9:30

C.I.T., 2315 Engineering

(C. S. BARRETT presiding)

Mechanical Properties of Solids

T1. Strain Amplitude Dependence of Internal Friction. G. S. BAKER AND J. S. KOEHLER, *University of Illinois.**—99.999% pure single crystals of lead exhibit four regions in their damping *versus* strain amplitude curve. At the lowest strain amplitudes ($<5\times10^{-7}$) the damping is amplitude independent. At higher strains (5×10^{-7} to 5×10^{-6}) the damping becomes strongly amplitude dependent. This is followed by a region of less or zero amplitude dependence, and at strain amplitudes less but comparable to the yield stress there is a final region of amplitude dependence. The behavior of 99.999% copper is similar, although the separation of the regions is less distinct. 99.99+% aluminum crystals show only one region of amplitude dependence which starts somewhere in the range from an order of magnitude below the yield stress to slightly below the yield stress, depending on past thermal and mechanical history. The presence of a static stress comparable to the oscillating stress necessary to cause amplidute dependence has no appreciable effect on the first two regions of copper and lead. In the case of aluminum the presence of a static stress lowers the oscillating stress necessary for amplitude dependence of the damping. Decreasing the temperature below room temperature shifts the curve of δ *vs* $\log\epsilon$ to higher strain amplitudes, leaving its shape unchanged for copper and aluminum.

* Supported by the Office of Ordnance Research.

T2. Internal Friction Changes During Aging of Aluminum-4% Copper.* B. S. BERRY, *Yale University* (introduced by A. S. Nowick).—The temperature dependence of the internal friction of Al-4% Cu is under investigation at various stages of aging, using a torsoin pendulum. Solution-treated and quenched specimens exhibit a small peak at 166°C (for 0.53 cps), which has an activation energy of approximately 28 kcal/mole. The strength of this peak falls by a factor of two on aging for a few hours at 200°C. After 6 hours, a second broader peak is noticeable at 120°C, which reaches a maximum size after 150 hours, with kinetics similar to those for the precipitation of the phase θ'. The fully formed peak, which has an activation energy of 22 kcal/mole, appears stable against further aging until the temperature is raised to 300°C. Several days aging at 300°C causes a large reduction in the strength of this peak. In addition to these peaks there is a smoothly rising temperature-dependent background which increases at first in the same manner as the second peak, but continues to increase during the 300°C aging treatment. Both polycrystalline and single-crystal specimens show essentially the same behavior.

* Work supported by the National Advisory Committee for Aeronautics.

T3. Effect of Impurities on Dislocation Damping. D. N. BESHERS, *University of Illinois.*†—Single crystals were prepared from 99.999% pure copper to which small amounts of gold had been added systematically. Measurements of internal friction as a function of amplitude of oscillation were made at temperatures from 25°C to 400°C. Results on pure copper confirm those of Marx. The smallest amount of gold added was sufficient to bring the initial decrement to values as low as any observed during these experiments. The alloy curves are substantially independent of temperature up to ~300°C. The curves of decrement *vs* amplitude obtained on the pure specimens are not easily fitted to any analytic expression. Those obtained from the alloy specimens fitted well to the expression $\Delta=\Delta_0+B\exp(-A/\epsilon)$. A similar expression $\Delta=\Delta_0+(B'/\epsilon)\exp(-A'/\epsilon)$ has been proposed by Granato and Lücke (to be published in the *Journal of Applied Physics*) working with a modification of Koehler's theory. The experiments cannot distinguish between the formulas.

* Now at the Naval Research Laboratory.
† Supported in part by the Office of Naval Research.

T4. Development of Etch Pits by Heating Copper Crystals to High Temperatures in High Vacuum. F. W. YOUNG, *University of Virginia* (introduced by N. Cabrera).—In order to study the development of etch pits and facets on different crystal faces, single-crystal spheres of copper were carefully polished, cleaned, and heated by induction heating to temperatures near the melting point in vacuua~5×10^{-9} mm Hg. In one set of experiments copper was evaporated from the surface of the crystal and condensed on the cold wall of the vacuum

vessel. Facets were formed parallel to the (111), (100), and (110) faces, and some etch pits were developed. On some crystals, spirals with large steps were developed around the (111) poles. In a second set of experiments the crystal was suspended in a copper cup which was heated with the crystal so as to approach equilibrium between crystal and vapor. Facets were also formed by this treatment, and a larger number of etch pits were formed in the surface. The number of etch pits per unit area varied with crystal face and with temperature of heating.

T5. Nucleation of Etch Pits at Dislocations.* N. CABRERA, *University of Virginia.*—A phenomenological analysis has been made of the conditions necessary for the nucleation of pits at dislocations. The energy of a dislocation is separated into strain and core energy, the latter being represented by a surface energy. The nucleation of a pit I_d is then compared to the nucleation everywhere else on the crystal surface I_e. The condition for pit formation requires I_d to be large with I_e being still small. This only occurs within well-defined limits. It is shown how those limits depend on the Burgers vector, the inclination of the dislocation with respect to the surface, the concentration of dislocations, etc. The application of this analysis to the formation of pits by evapoartion and the influence of impurities will be discussed.

* Work supported by the Office of Naval Research.

T6. Dislocation Etch Pits on Silicon. S. M. CHRISTIAN AND R. V. JENSEN, *RCA Laboratories.*—Etching techniques are described for detecting edge, screw, and composite type dislocations in silicon. The etchants used to reveal the dislocation pits resemble the standard CP-4 etchant with addition of copper nitrate. Screw type dislocations, rarely found in germanium, were found with high density, 10^4-10^5 cm^{-2}, in all silicon crystals examined. The indicated Burgers vectors are 10^4-10^5 A, indicating a closure failure as great as 20 000 atoms. The largest Burgers vectors previously reported were less than 10^3 A, in SiC and gold.[1] Impurity particles on the growth surface have been suggested as possible sources of spiral dislocations. In silicon, particles of SiC or SiO_2 might nucleate the spirals. Edge-type dislocation densities were comparable to those found in germanium, 10^3-10^5 cm^{-2}, but the composite type densities were in the range $1-5\times10^8$ cm^{-2}, compared to 10^6-10^7 reported for germanium.

[1] A. Verma, *Crystal Growth and Dislocations* (Academic Press, Inc., New York, 1953), p. 144.

T7. Slip in NaN_3 and KN_3 Crystals.* RUSSELL W. DREYFUS,† *Picatinny Arsenal,* AND PAUL W. LEVY, *Brookhaven National Laboratory.*—When sodium or potassium azide crystals that have undergone shock or strain are observed in a polarizing microscope brightly colored bands appear. Viewed along the *c*-axis these bands intersect at 120° in the hexagonal NaN_3 and at 90° in the tetragonal KN_3. Each band is a plane extending through the crystal at an angle to the *c*-axis. From the thickness of the crytsal and the width of the band one finds that these are (110) planes in NaN_3 and (112) planes in KN_3. Interference microscope measurements indicate that there is a step on the surface where these planes emerge and the steps at opposite ends of the same plane are of different height. From these observations one concludes that slip has occurred on planes of dense packing and that along these planes the crystal is under stress. Also, the region along the plane exhibits birefringence due to strain or to misorientation of the lattice. This birefringence accounts for the color of the bands. Gamma-ray induced decomposition occurs readily at the intersection of the slip plane and the surface, so that a deep groove appears at this line when the crystals are exposed to 10^7r.

* Under the auspices of Picatinny Arsenal and the U. S. Atomic Energy Commission.

† Guest Scientist, Brookhaven National Laboratory.

T8. Anisotropic Strain Near a Vacancy or an Interstitial in Lennard-Jones Crystals. GEORGE L. HALL, *University of Virginia* (introduced by N. Cabrera).—An atomic theory of the lattice distortion around point imperfections in cubic crystals obeying arbitrary central forces is presented. The crystals are assumed to be at 0°K and under arbitrary pressure. Application of the theory is made to the particular cases of the vacancy and the interstitial in f.c.c. crystals obeying Lennard-Jones 6–12 potentials. It leads, for both defects, to an anisotropic strain which is radially outwards along the cubic axes and, roughly speaking, negative elsewhere. The contribution of the distortion to the energy of formation of a vacancy increases with positive pressure. There is presented also a more approximate theory which utilizes linear elasticity. The usual problems concerning tensions and boundary conditions at the surface of a cavity associated with the defect are eliminated by replacing a crystal with a defect by a perfect crystal acted upon by a known body-force. The elastic approach yields a spherically symmetric configuration of displacement around a vacancy which is in good agreement with the atomic solution but which disagrees with the usual assumption of a $1/r^2$ law of displacement.

T9. Dislocations at Compositional Fluctuations in Germanium-Silicon Alloys. A. J. GOSS,* K. E. BENSON, AND W. G. PFANN, *Bell Telephone Laboratories.*—Unusual arrays of dislocations have been found in germanium-alloy single crystals grown from the melt. The arrays are presumably layers of edge dislocations which lie parallel to successive positions of the liquid-solid interface during freezing. They arise from microscale fluctuations in solute concentration, and hence of lattice constant, at the interface. The dislocations form presumably because they reduce the energy of elastic strain between adjacent crystal layers which differ in lattice constant. They have been observed in Ge-6% Si, Ge-0.2% Sn, and Ge-~0.2% B single crystals, and also at $p-n$ step junctions, but have not been found in Ge or Si crystals containing $<10^{-4}$ atomic percent solute. Etching Ge alloys in CP-4 reveals the dislocations as etchpits, and the fluctuations in solute concentration as striae parallel to interface positions. Dislocations appear only at certain striae, presumably because they are formed only if the concentration gradient exceeds a critical value related to the elastic strain required to form a dislocation. These microscale fluctuations in solute concentration provide an effective mechanism for the origin of dislocations in melt-grown crystals.

* Now with Marconi Research Establishment, Chelmsford, Essex, England.

T10. Stress Relaxation in Germanium at Ultrasonic Frequencies. J. O. KESSLER, *RCA Laboratories.*—An ultrasonic resonance method[1] has been employed to investigate the behavior of high-purity germanium single crystals with alternating longitudinal stress at 40 and 120 kilocycles. In particular, measurements have been made of the logarithmic decrement (δ) at relative strains $\leqslant 10^{-6}$, in a temperature range between 270°C and 750°C. A pronounced peak has been observed at 382°C, in the curve δ *vs* T, for the 40 kc case, and at 420°C for 120kc. An exponential rise of δ with T occurs for $T\geqslant 500$°C. In measurements below 500°C, δ did not rise above 3×10^{-5} for any specimen tested. This low level may well account for the fact that the peak was not observed in earlier experiments.[2] The phenomenon was found to be essentially unaffected by changes in impurity content of the Ge, corresponding to room-temperature resistivities from two to fifty ohm-cm, *n*- or *p*-type, or by changes in crystallographic direction of the vibrational mode. It has been found that significant changse may be brought about by alteration of the crystal perfection, i.e., through increase or decrease of the dislocation density by several orders of magnitude. The data

will be interpreted as a stress induced relaxation effect caused by the motion of intrinsic defects.

[1] J. Marx, Rev. Sci. Instr. **22**, 503 (1951).
[2] Baker, Slifkin, and Marx, J. Appl. Phys. **24**, 1331 (1953).

T11. Change in Density of KCl with Plastic Deformation. W. VAUGHAN,* W. LIEVO, AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—The change in density of single crystals of potassium chloride has been measured as a function of plastic deformation. Measurements were made on twenty-eight samples. It was found that the smallest deformation for which a measurable change in density occurred was around 11%. The density decreased at a rate of $1.88 \cdot 10^{-5}$ g/cm³ for each percent of deformation. Further measurements showed that the density change could be annealed out by a ten-minute anneal at 350°C. Surface hardness tests with the Tukon Tester showed no appreciable change in hardness between deformed crystals that had been subjected to the ten-minute anneal and crystals that were deformed and unannealed.

* Present address: United States Naval Research Laboratory.

T12. Dispersion of a Longitudinal Strain Pulse in an Elastic Cylindrical Bar.* GEORGE R. FOX AND C. W. CURTIS, *Lehigh University.*—An air shock has been used to apply pressure suddenly to the end of a magnesium bar 1.5 inches in diameter. The resulting strain has been measured as a function of time with barium titanante gauges at distances from 1 cm to the equivalent of 14 m from the stressed end. The strain-time records clearly show oscillations associated with dispersion.[1-3] Beyond approximately 20 diameters from the end, all main features of the oscillations are predicted using asymptotic solutions of a Fourier integral constructed from sinusoidal waves obeying the Pochhammer-Chree frequency equation. In particular, the solutions predict correctly that the head of the pulse should travel faster than the "bar velocity" determined by Young's modulus. Amplitudes and periods of observed oscillations following the head can be calculated from elastic constants and geometry alone. Second mode vibrations are observed at the times and with the frequencies predicted.

* Work supported in part by U. S. Army, Office of Ordnance Research.
[1] R. M. Davies, Phil. Trans. Roy. Soc. (London) **A240**, 375 (1948).
[2] E. A. Ripperger, Proc. First Midwestern Conf. Solid Mech., Univ. of Illinois (1953).
[3] C. W. Curtis, J. Appl. Phys. **25**, 928 (1954).

T13. Convergent-Beam X-Ray Analysis of Mosaic Structure in Polycrystals. CHESTER R. BERRY, *Eastman Kodak Company.*—A simple x-ray diffraction method was used to measure the mosaic misalignment and the number of dislocations in the crystals of silver halide precipitates and of nickel foils where the grain sizes were in the range from a few tenths of a micron to a few microns. The experimental arrangement is such that separate diffraction spots are produced by each crystallite and the width of a spot is determined primarily by the mosaic nature of the grain. It appears that measurements of angular misalignment can be made down to the limit imposed by the natural width of the x-ray spectrum lines. In general, either cold work or the presence of a substitutional impurity causes broadening of the diffraction spots. However, it is possible to incorporate impurities without producing broadening or dislocations. In spite of a 1% substitution of iodide impurity in silver bromide, crystals were produced which appear to have no edge dislocations.

SATURDAY MORNING AT 9:30

C.I.T., 2210 Engineering

(S. MILLMAN presiding)

Oliver E. Buckley Lecture

U1. Magnetic Crystallography by Neutron Diffraction. C. G. SHULL, *Brookhaven National Laboratory* (40 min.)

Invited Papers

U2. Temperature Dependence of Ferromagnetic Anisotropy. F. KEFFER, *University of Pittsburgh.* (30 min.)

U3. Ferromagnetic Absorption at High Microwave Signal Levels. H. SUHL, *Bell Telephone Laboratories.* (30 min.)

SATURDAY MORNING AT 9:30

C.I.T., Industrial Administration

(J. M. LUTTINGER presiding)

Solid-State Theory

UA1. Critical Points of Function of Three Variables. HERBERT B. ROSENSTOCK, *Naval Research Laboratory.*—The following situation arises in several solid state problems: one has explicitly a secular equation $f(k_1,k_2k_3; E) = 0$, would like to solve this for the dispersion relation $E = E(k)$ and from this obtain the density of states $g(E)dE$, but is stymied by the excessive complexity of the secular equation. Often however, the secular equation simplifies sufficiently on a closed two-dimensional boundary surface of k-space (i.e., ~the Brillouin zone boundary) that $E(k)$ can be found explicitly on that

boundary.[1] Now critical points of $E(k)$ have been shown[2] to determine the qualitative features of the $g(E)$ function (critical points are points at which all three $\partial E/\partial k_i$ vanish; they can be maxima, minima, or saddle points depending on the signs of the second derivatives); and one would therefore like to know to what extent the number and nature of critical points of a function inside a region is determined by the boundary conditions. We find that simple topological arguments enable us to use the number and nature of two-dimensional critical points on the boundary (defined analogously to three-dimensional critical points in terms of a local coordinate system) to compute the difference between the number of three-dimensional saddle points and three-dimensional maxima or minima inside. Possible algebraic methods for finding an upper limit on the total number of critical points will be suggested.

[1] For a discussion of this, see H. B. Rosenstock, Phys. Rev. **97**, 290 (1955).
[2] L. Van Hove, Phys. Rev. **89**, 1189 (1953).

UA2. Specific Heat of a One-Dimensional Lattice. PAUL M. MARCUS AND ANTHONY KENNEDY, *Carnegie Institute of Technology*.—The frequency spectrum of a one-dimensional monatomic lattice is well known but its specific heat has apparently not been carefully calculated. As part of a new method of finding the specific heat of three-dimensional lattices, based on the one-dimensional case, this calculation has been made in several ways. The sensitive plot of (θ_{eq}/θ_0) *vs* (T/θ_0), where θ_{eq} is the equivalent one-dimensional Debye θ and θ_0 the limiting value at 0°K, shows a typical parabolic behavior near 0°K, dropping off by 5% at $T/\theta_0=1/15$. This variation of θ_{eq} with T is quite similar to that found in three-dimensional cases but rather different from the result given by Blackman[1] which shows θ_{eq} leveling off for small T at much smaller values of T/θ_0 and dropping by 5% from the limiting value at about $T/\theta_0=1/27$. Expansions of the specific heat in powers of T/θ_0 and θ_0/T have been used in the evaluation; by refined summation procedures the former may be summed for $T/\theta_0 \lesssim 0.1$ and the latter for $T/\theta_0 \gtrsim 0.1$, thus covering all values of T.

[1] M. Blackman, Proc. Roy. Soc. (London) **A148**, 365 (1935).

UA3. On the Normal Mode Distribution in f.c.c. Crystals.* LEWIS SALTER AND ROBERT WOODS, JR., *Wabash College* (introduced by Robert Woods, Sr.).—The use of a least squares polynomial fitted to the first few even positive moments of the frequency spectrum[1] gives a good representation of $g(\omega)$ at intermediate and high frequencies but fails at low frequencies. On the other hand, Houston's method[2] of analytic representation of $g(\omega)$ seems satisfactory at low frequencies but fails at higher frequencies due to presence of spurious singularities inherent in the method. We have investigated the use of a composite $g(\omega)$, low-frequency values obtained by Houston's method and high-frequency values from the moment polynomial representation; application was made to the two cases investigated by Leighton.[3] $\Theta_D(T)$ curves obtained for the two cases are compared with those obtained by Leighton. The agreement is satisfactory for both cases (within 0.5% over the entire temperature range for the nearest neighbor model).

* Supported by a grant from the Research Corporation
[1] Montroll, J. Chem. Phys. **11**, 481 (1943).
[2] Houston, Revs. Modern Phys. **20**, 161 (1948).
[3] Leighton, Revs. Modern Phys. **20**, 165 (1948).

UA4. Coupling between Acoustical and Optical Lattice Modes. WALTER A. HARRISON, *University of Illinois*.—The lattice vibrations of crystals possessing two atoms per unit cell and Hooke's law interactions have been considered. Acoustical and optical plane waves were constructed by perturbation theory for small wave numbers. It was found that the acoustical modes have a simple continuum-like form and the optical modes are sinusoidally-modulated infinite-wavelength modes if there exists a center of symmetry at each atomic site. There may be an admixture of acoustical and optical modes which is first order in the wave number when such centers of symmetry do not exist. The form of the admixture was found for crystals of the zinc blende and of the diamond structures. The magnitude of the admixture was found to depend upon a single coupling constant for each crystal. In the case of the zinc blende structure this constant was evaluated in terms of the piezoelectric constant. For the diamond structure this constant was evaluated in terms of the elastic constants by constructing a three-parameter force model for atomic interactions. Particular notice was taken of the requirement that the force model be invariant under bulk rotations of the crystal.

UA5. Topological Treatment of Lattice Vibration Spectra. JAMES C. PHILLIPS.* *University of Chicago* (introduced by M. H. Cohen).—Important features of the frequency distribution of lattice vibrations arise from the critical points of the frequency surfaces in k-space. Van Hove was the first to study critical points by topological methods, thus obtaining minimum numbers for the various kinds of analytic critical points.[1] His results have been extended by using general group-theoretical, perturbation, and more detailed topological methods to yield the most likely number of critical points to be expected from a given secular equation. Our results include, and in fact depend essentially on, treatment of the various kinds of nonanalytic degenerate critical points, which had not been analyzed previously.[2] Applications to several lattices will be discussed.

* General Electric Fellow.
[1] L. Van Hove, Phys. Rev. **89**, 1189 (1953).
[2] See H. B. Rosenstock, Phys. Rev. **97**, 290 (1955).

UA6. Lattice Sums of Coulomb Potentials Over Semi-Infinite Lattices in Ionic Crystals.* ROBB THOMSON, *University of Illinois*.—In a recent letter, Kanzaki[1] has suggested that the emergence point of an edge dislocation in AgCl may represent an effective charge on the surface of the crystal. We have developed a method for performing lattice sums over semi-infinite lattices of one or more dimensions which may be applied to dislocation problems in ionic crystals. It leads to an alternative derivation to the one already given by Seitz and Mott that the incipient vacancy at a jog in an edge dislocation has an effective charge of $e/2$ in a lattice of the NaCl type. The potential due to a (110) edge dislocation emerging on a (100) surface is a complicated expression containing a term which varies inversely as the first power of the distance from the point of emergence. Applications to problems of emergence on (110) surfaces are in progress.

* Supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] H. Kanzaki, Phys. Rev. **99**, 1888 (1955).

UA7. Self-Consistent Approach to the Polaron Mass.* T. D. SCHULTZ, *M. I. T.*—A simple electron-lattice product function determined from a variational calculation of the polaron self-energy cannot be a good approximation to the ground-state function since the best product function is localized and the ground state is not. One must thus symmetrize any localized function.[1] In principle, a better result would be obtained if the symmetrization were to precede the variational calculation, but then the latter becomes too difficult. One may, however, modify the Hamiltonian so that the modified Hamiltonian has approximately localized eigenfunctions which, on symmetrization, yield the momentum eigenfunctions of the original Hamiltonian. It is then useful to seek one of these localized functions variationally with a simple product function or a linear combination of such functions, since such a procedure is expected to converge. The appropriate modification is determined by two natural self-

consistency conditions which also give a more sensitive approach to the effective polaron mass than other variational theories starting with a simple product function. The method is illustrated for a simple two particle system and discussed in its application to the polaron.

* Supported in part by the National Science Foundation and in part by the Office of Naval Research.
[1] G. Höhler, Z. Physik **140**, 192 (1955).

UA8. A One-Dimensional Treatment of the Effective Mass in Diatomic Semiconductors. I. ADAWI,* *RCA Laboratories* (introduced by Harwick Johnson).—The energy band structure of one-dimensional crystals has been calculated using a Kronig-Penney model. The width of the forbidden band and the effective masses of electrons are determined as a function of the asymmetry of atomic spacing and potential. Numerical calculations for a specific average potential show that the effective mass changes monotonically with asymmetry without a minimum in the finite asymmetry range. This result differs from the findings of B. Seraphin.[1] While this model does not describe an actual crystal in that it is one dimensional, the results are nevertheless instructive inasmuch as it gives the qualitative trend at a given point in the reduced zone. However, in cases where the valence and/or the conduction band edges switch over from one position in the reduced zone to another, as Herman[2] has described, a one-dimensional model is not applicable.

* Presently at Cornell University.
[1] B. Seraphin, Z. Naturforch. **9a**, 450 (1954).
[2] F. Herman, J. Electronics, Ser. 1, **1**, 103 (1955).

UA9. Band Structure of Semiconductor Alloys with Locally Varying Composition. H. KROEMER, *RCA Laboratories.*—The width of the forbidden band of a semiconductor alloy, such as a Ge-Si alloy is a function of the composition of the alloy. In crystals whose composition is not constant but a function of the position within the crystal, one then obtains a nonuniform band gap within the crystal. The paper deals with continuous rather than abrupt changes in composition. It will be shown that it is legitimate, then, to draw an energy band scheme with nonuniform band widths and effective masses. The local band structure is equal to that of a homogeneous crystal with the same composition as that of the inhomogeneous crystal at the location under consideration. The dynamics of electrons and holes is still governed by Newton's law if the local effective mass is used and if the slope of the proper band is used as the driving force. The latter result holds regardless whether the band slope results from an external electric field or from an internal change of the band gap. As a consequence, the forces acting upon electrons and holes are no longer equal and opposite. One can, for example, obtain structures in which only one kind of carrier is being accelerated on in which both kinds are accelerated in the same direction.

UA10. Exciton Band Structure in Covalent Crystals. G. DRESSELHAUS, *University of Chicago.*—Using the effective mass formalism for degenerate energy surfaces, an analysis has been made of the theoretical exciton spectrum in covalent crystals. If the extrema of the conduction and valence bands are both at the center of the Brillouin zone, one would also expect a minimum in the exciton band at that point. Other positions of the energy band extrema imply that the exciton band minimum will occur at some general point in the zone. The direct creation of excitons by photons is allowed only for exciton states at $\mathbf{k}=0$. Unless the exciton band minimum lies at the center of the zone, one would create excitons in excited translational states. The absorption lines due to transitions to excited translational states would in general be masked by the continuous absorption due to indirect transitions from the valence to the conduction band. The exciton absorption spectrum in silicon and germanium has presumably not been observed for this reason. Exciton creation by indirect transitions will also be discussed.

UA11. Effective Mass Theory and the Crystal Momentum Operator. M. H. COHEN, *University of Chicago.*—A very simple description of the motion of electrons in perturbed periodic potentials was achieved by Adams through the systematic use of the crystal momentum operator.[1] Similarly, a modified crystal momentum representation simplifies the recent presentations of effective mass theory for degenerate bands.[2] The use of Brillouin perturbation theory permits easy extension to the case of nearly degenerate bands, important for magnetic problems. The representatives of operators such as position, velocity, momentum, etc. are obtained. It is found that the principal effect of spin-orbit coupling is to modify the velocity operator. The contribution of orbital angular momentum within the unit cell to the magnetic moment, independently discovered by Luttinger,[3] is discussed. Some corrections to the representatives of arbitrary functions of position as given by Adams are found necessary.

[1] E. N. Adams II, J. Chem. Phys. **21**, 2013 (1953).
[2] J. M. Luttinger and W. Kohn, Phys. Rev. **97**, 869 (1955).
[3] J. M. Luttinger, Phys. Rev. (to be published).

UA12. Considerations on the Band Structure of Bismuth. E. I. BLOUNT,* *University of Chicago.*—Group theoretical techniques[1] have been used to find the probable locations of the extrema of the energy bands of the Group V semimetals. The form of the Hamiltonian in the effective mass procedure, including the recently discovered extra terms[2] in the interaction with the magnetic field have been determined for these points. The outstanding features of the band structure of bismuth are the slight overlap between valence and conduction bands, and the small energy differences which must be assumed in order to explain the minute effective mass.[3] It is suggested that both of these features can be understood by considering the Bi structure as a perturbed simple cubic lattice. Then the levels with nearly equal energies are derived from originally degenerate levels. Plausible arguments can be made about the actual order of levels. It is assumed that the bonding is essentially due to p-orbitals. Deviation from the cubic structure may be tentatively explained as due to lowering of the one-electron energy levels by the perturbation.

* National Science Foundation Predoctoral Fellow.
[1] See, e.g., G. Dresselhaus, Phys. Rev. **100**, 580 (1955).
[2] M. H. Cohen (previous abstract); J. M. Luttinger, Phys. Rev. (to be published).
[3] D. Schoenberg, Trans. Roy. Soc. (London) **A245**, 1 (1952); B. Abeles and S. Meiboom, Phys. Rev. (to be published).

UA13. An Estimate of the Minimum Width of the Halogen Band in NaCl.* R. C. CASELLA, *University of Illinois* (introduced by F. Seitz).—It has been suggested by Pariatt and Jossem that the halogen band in NaCl may be considerably narrower than 4.4 ev, as predicted by Shockley. To obtain a lower limit on the width of the band, a model is assumed in which the Cl^- ions in the Cl−Cl lattice for NaCl are imagined replaced by neutral argon atoms. The crystal potential is assumed to be a sum of spherically symmetric atomic potentials, which are calculated in the free-electron-exchange approximation of Slater. The method of tight binding is employed. The wave function is expressed as a linear combination of Bloch sums of $3p$-orbitals with x, y, and z symmetry. The secular equation has been factored, in the two-center, nearest-neighbor approximation, for k along the (100), (110), and (111) directions. The energy integrals are calculated analytically. A minimum band width of about 1.0 ev is obtained. The error due to neglect of three-center integrals, nonorthogonality of Bloch sums, second-nearest neighbors, and the influence of the $3s$-band is estimated to be of order 30%. The actual value of the width is believed to lie much

closer to Shockley's result, which probably represents an upper limit since his calculation is based upon Hartree orbitals determined without exchange.

* Supported in part by OSR-ARDC and in part by Horizons Inc.

UA14. Time-Dependent Behavior of Metal—Semiconductor Rectifying Barrier.* B. R. GOSSICK, *Purdue University.*—The barrier voltage response $f(t)$ to an impulse current has been calculated for small variations from the ac admittance. Although the expression obtained for $f(t)$ is complicated, it may be approximated under representative conditions (depending on bias and nature of the contact) by one of the following functions: e^{-t}, $e^{t}erfc\,t^{\frac{1}{2}}$, or $e^{-at}\{[1-2C(t)]\cos t + [1-2s(t)]\sin t\}$ with time t in appropriate units. The functions $C(t)$ and $S(t)$ are the well-known Fresnel integrals.

* This invstigation was supported by the U. S. Signal Corps.

SATURDAY MORNING AT 9:30

C.I.T., 100 Porter

(W. H. BRATTAIN presiding)

Surface Phenomena and Diffusion in Semiconductors

V1. Effect of Space Charge on the Work Function of Semiconductors and Insulators. EARL CALLEN, *Department of Defense.*—Careful experimentation has shown that the work function of semiconductors does not depend on the doping density. For example, Dillon[1] finds the work function of a (100) face of nearly intrinsic germanium to be less than that of (111) face of 10 ohm-cm n-germanium by 0.02 ev, while the difference in Fermi level heights is here about 0.05 ev. Bardeen[2] showed that the discrepancy between Fermi level shift and work function change could be attributed to Tamm or impurity surface states. The recent experiments have been on exceedingly clean surfaces. It is here suggested that, in coming into thermal equilibrium with the vapor outside, electrons escape from the crystal, leaving a positive space charge region beneath the surface of an insulator or semiconductor which causes the electrostatic potential to curve in just such a way as to hold the work function more or less independent of the Fermi level. The effect of space charge also accounts for the observation that all faces of a semiconductor have much the same work function, while a good metal like copper shows work function differences as high as 0.75 ev. The development of the final charge and potential distributions will be described in detail.

[1] J. A. Dollen, Bull. Am. Phys. Soc. 1, 53 (1956).
[2] J. Bardeen, Phys. Rev. 71, 717 (1947).

V2. An Effect of Water Vapor on Germanium Surface Potential. A. R. HUTSON, *Bell Telephone Laboratories.*—Relative humidity is known to influence the surface potential of germanium. For all but the very driest of ambients, Law[1] has shown that the germanium surface is covered by a film of water whose thickness is governed by humidity. Kingston[2] has observed the surface potential of a germanium sample as a function of humidity alone in a situation in which there is good evidence that the surface potential is "clamped" by donor-atom surface states. We treat the term in the surface donor energy level which is due to dielectric polarization of the water film and has its origin in the discrete nature of the surface-state charges. A calculation of this term as a function of water-film thickness, together with Law's water vapor adsorption isotherm, is shown to quantitatively account for Kingston's observations.

[1] J. T. Law, J. Phys. Chem. 59, 67 (1955).
[2] R. H. Kingston, Phys. Rev. 98, 1766 (1955).

V3. Structure of Surface States on Silicon from Conductance Measurements of n-Type Inversion Layers. G. A. DEMARS, H. STATZ, L. DAVIS, JR., AND A. ADAMS, JR., *Raytheon Manufacturing Company.*—n-type inversion layers on p-type silicon are observed when an etched surface is exposed to dry ammonia. Measurements of the steady-state conductance of the inversion layer as a function of bias voltage have been made on bars with a transistor-like n-p-n structure. The measurements can be interpreted by assuming a large total density of states. By careful analysis it is possible to determine an upper limit of the thickness of the oxide film. Depending on the degree of oxidation, thicknesses of the order of 10 A or more have been obtained. Nonsteady-state conductance measurements are more difficult to interpret than those made on p-type inversion layers. There are states at the silicon-oxide interface in the upper half of the energy gap with a density of the order of 10^{12} states/cm^2. Detailed results will be presented.

V4. Field Effect and Surface Conductance of a Cleaned Germanium Surface.* P. HANDLER, *University of Illinois.*—Large changes in the field effect mobility and surface conductance have been observed due to the adsorption of oxygen on a cleaned germanium surface. A thin 40 ohm cm n-type sample of germanium was cleaned in vacuum using the argon bombardment techniques of Farnsworth *et al.* After the sample had been gradually cooled to room temperature the sample exhibited an excess conductivity of 250–300 micromhos/square. Admittance of oxygen to the system at pressures of 10^{-7} mm Hg changed the conductance markedly. The conductance first increases then decreases to a value close to that of the uncleaned surface, indicating no large bulk changes as a consequence of the treatment. The adsoprtion of oxygen on the surface is irreversible since pumping away the oxygen will not change the conductance. The field effect mobility of the clean surface is low and dependent upon the temperature and time anneal. As oxygen is introduced into the system the field effect mobility increases to about 4 to 5 times its clean surface value and then decreases. The maximum of the field effect mobility can be as high as 200 cm^2/v sec and occurs a little after the maximum in the conductance. The clean surface condition can be reproduced by heating the sample to 500°C for 30 min in high vacuum.

* Supported by the Office of Naval Research.

V5. Adsorption of Oxygen on Germanium.* R. SUN,† *University of Illinois.*—Adsorption of oxygen on powdered germanium surfaces has been measured at temperatures in the range 200° to 500°C. Reproducible results were obtained if the specimen was initially cleaned by heating in vacuum at 650°C. The amount adsorbed as a function of time was observed by following the decrease in pressure in a closed system after injection of a known amount of O_2. Injection pressures of 30 to 150μ were used. The surface area as esti-

mated by the BET method was about 10^4 cm². It was found that the rate of adsorption is roughly proportional to pressure and decreases rapidly with increasing coverage. The activation energy, increasing with coverage, varies from 20 to 25 kcal. The total amount adsorbed corresponds to less than a monolayer.

* Supported by Office of Naval Research.
† Now at Franklin Institute.

V6. Electric Properties of Ion-Bombarded Germanium Surfaces.* S. H. AUTLER, A. L. MCWHORTER, AND H. A. GEBBIE,† *Lincoln Laboratory.*—Measurements of resistance, field effect, and photoconductivity have been made on (100) surfaces of near-intrinsic *n*-type germanium samples, which were subjected to the cleaning procedure developed by the Brown University group.[1] The samples were outgassed at around 600°C for about 60 hours in vacuum ($<10^{-8}$ mm), by passing current through spot-welded molybdenum contacts. Argon-ion bombardment increased the resistance by over 25% and greatly reduced the field effect and photoconductivity. Upon annealing, the resistance decreased to less than its prebombardment value and the photoconductivity substantially recovered. The field effect increased markedly and had a flat frequency response from 10 to 1000 cps, with a sign indicating a *p*-type surface. Exposure of the sample to oxygen at a pressure of 10^{-3} mm caused the resistance to increase nearly 50% while the photoconductivity decreased or remained the same, depending on the sample. The amplitude of the field effect increased by a factor of 2 or 3, with the frequency dependence and sign remaining unchanged. These changes, upon exposure to oxygen, occurred over a period of minutes indicating that the rate is not determined by the oxygen pressure.

* The research reported in this document was supported jointly by the U. S. Army, Navy, and Air Force under contract with Massachusetts Institute of Technology.
† Now at the Department of Physics, The Johns Hopkins University, Baltimore, Maryland.
[1] Farnsworth, Schlier, George, and Burger, J. Appl. Phys. **26**, 252 (1955).

V7. Long-Time Changes in Work Function.* G. W. PRATT, JR., AND H. H. KOLM, *Lincoln Laboratory.*—It has been found that the work function of a Ge, Si, or Au surface can be altered by prolonged illumination by as much as one-tenth of a volt. In the dark this change in work function decays to equilibrium in about 30 min following the same logarithmic law obeyed by the decay of the contact potential difference reported earlier to be induced by a dc electric field.[1] Measurements of the decay of the light and field induced effects as a function of temperature indicate that the slope of the contact potential *vs* $\log(t)$ plot is directly proportional to T. These effects have been studied as a function of the pressure and ambient. The changes in work function caused by applied fields or illumination appear to be of the same nature as the conductance changes resulting from these disturbances found by Morrison.[2] The possibilities that a chemisorbed atom can act as a trap for an additional electron or that it is the act of chemisorption itself which serves to trap electrons will be discussed.

* The research in this talk was supported jointly by the U. S. Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] H. H. Kolm and G. W. Pratt, Jr., Phys. Rev. **99**, 1644 (1955).
[2] S. R. Morrison, Phys. Rev. **99**, 1655 (1955).

V8. First Occurrence Probabilities in Stochastic Physical Processes.* JOHN E. ROBINSON, *Argonne National Laboratory.*—In physical instances of stochastic processes, it is often desirable to know the probability, f, of first occurrence of a given situation as a function of time or of position in a discrete sequence of events. Most frequently, however, it is the probability, g, of *any* occurence that is given by a tractable theoretical computation which comprehends the boundary conditions. Now for a time-wise continuous process $g(t)$ is expressible as an infinite series of positive terms each of which is a multiple convolution of $f(t)$.[1] It is shown by means of Laplace transforms that this relationship may be inverted to give $f(t)$ in terms of $g(t)$, a similar series being obtained but with alternating signs. It is further shown that for a time-wise discrete sequence an analogous inversion can be performed to give f in terms of g. The inversions should hold quite generally and independently of the boundary conditions. Application to the results of Montet[2] on the diffusion of C^{14} in graphite will be discussed.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] See, e.g., R. M. Noyes, J. Chem. Phys. **22**, 1347 (1953), Sec. II.
[2] Montet, Kurs, and Hennig, Phys. Rev. **100**, 1261 (A) (1955).

V9. Interstitialcy Migration and the Einstein Relation in Ionic Crystals. C. W. MCCOMBIE,* *University of Illinois,* AND A. B. LIDIARD, *A. E. R. E., Harwell, England* (introduced by F. Seitz).—In an interstitialcy jump an interstitial ion pushes a lattice ion into an interstitial position and occupies the vacated site. The displacement of the ions involved, and so the jump distance of a tracer ion is in general less than the distance of an interstitialcy. Moreover, successive jumps of a tracer are not independent. These two effects make the ratio of tracer diffusion to ionic conductivity less than the Einstein value. If the two ion displacements in a jump are supposed colinear and allowance is made for a contribution from vacancy migration, the predicted departure from the Einstein ratio is greater than that found experimentally in AgCl.[1] If the ion displacements are supposed noncolinear, the predicted departure from the Einstein value would be smaller than observed. Roughly equal frequencies for colinear and noncolinear (⟨110⟩ interstitialcy displacement) jumps would give agreement with experiment, but other mechanisms may be important.

* Commonwealth Fund Fellow on leave of absence from the University of Aberdeen, Scotland.
[1] W. D. Compton, Phys. Rev. (to be published).

V10. Diffusion of Aluminum in Silicon. B. GOLDSTEIN, *RCA Laboratories.*—The diffusion of aluminum in single-crystal silicon has been studied in the region from 1200°C to 1400°C by measuring the distance a *p-n* junction has migrated from a liquid-solid interface. At high temperatures aluminum from an Al-Si alloy melt is deposited into the underlying solid silicon and furnishes the source of the diffusing impurity. Thus, the source is introduced within the volume of the crystal. The experiment is carried out on two samples of silicon with different resistivities. This enables a determination of D independent of the source concentration C_0. For diffusion distances up to 10 mils, $\sqrt{t}$ behavior was found as expected from theory. In the temperature range studied, D varies from 10^{-10} to 10^{-9} cm²/sec with an activation energy of about 3.9 ev. From a knowledge of D, C_0 the source concentration of aluminum initially deposited in the silicon can be calculated. C_L, the concentration of aluminum in the alloy melt is known from a phase diagram. Thus, the distribution coefficient $k=C_0/C_L$ can be determined at the temperature of diffusion. The variation of k with temperature thus determined can be expressed in the form $k=k_0(\exp^{-E/kT})$, where E corresponds to a difference in the heat of solution of aluminum in the alloy melt and in the silicon and is about 1 ev.

V11. Self-Diffusion of Silver in Silver Bromide. ROBERT J. FRIAUF, *University of Kansas.*—The self-diffusion coefficient of silver in single crystals of AgBr has been determined by standard radioactive tracer techniques, with simultaneous measurements of electrical conductivity. Observations between 250 and 350°C yield diffusion coefficients which are smaller than values calculated from the conductivity according to the normal Einstein relation by a factor of approximately 0.60. This discrepancy can be accounted for by applying the

Bardeen-Herring correction for the diffusion of radioactive tracers if it is also assumed that most of the transport of interstitial ions occurs by the interstitialcy mechanism proposed by Seitz. With known mobility ratios and values of the Bardeen-Herring correction factor of 0.80, 1.00, and 0.33, respectively, for vacancy, interstitial, and interstitialcy mechanisms (kindly communicated by R. Maurer), calculated diffusion coefficients are smaller than observed values if the interstitialcy mechanism predominates. Conceivably, diffusion of silver also occurs through neutral vacancy pairs, but this appears unlikely. On the other hand, calculated and observed diffusion coefficients can be brought into fair agreement by supposing that only two-thirds of the interstitial ions move by the interstitialcy mechanism. Diffusion measurements in progress at higher temperatures, where the anomalous rise in conductivity occurs, may give further insight.

SATURDAY AFTERNOON AT 2:00

C.I.T., 2210 Engineering

(CHARLES KITTEL presiding)

DSSP Symposium on Semiconductors

W1. Elastoresistance Effect in Germanium. E. N. ADAMS, *Westinghouse Research Laboratories.* (30 min.)

W2. Impurity-Band Phenomena in Semiconductors. H. FRITZSCHE, *Purdue University.* (30 min.)

Business Meeting of the Division of Solid-State Physics

W3. Galvanomagnetic Effects in the Germanium-Silicon Alloys. M. GLICKSMAN, *RCA Laboratories.* (30 min.)

W4. Imperfections in Nearly Perfect Silicon. W. L. BOND, *Bell Telephone Laboratories.* (30 min.)

SATURDAY AFTERNOON AT 2:00

C.I.T., Industrial Administration

(F. C. NIX presiding)

Order-Disorder Phenomena

X1. Long-Range and Short-Range Order in $CuAu_3$.* B. BATTERMAN, *M. I. T.*—It was shown by Hirabayashi[1] that ordering takes place for the composition $CuAu_3$ with a reported critical temperature of $T_c=243°C$. By observing the disappearance of low-order superstructure reflections, the critical temperature for 75 atomic percent Au has been fixed at $T_c=199\pm3°C$. From integrated intensity measurements of the 100 and 110 reflections, a long-range order parameter of approximately $S=0.8$ has been found for samples long-annealed just below T_c. Annealing times are of the order of several weeks, and there is x-ray evidence of small antiphase domains. Measurements of critical temperature *vs* composition indicate an asymmetry about the 75% composition, with a higher T_c at lower Au compositions. From measurements of the diffuse scattering from a single crystal of $CuAu_3$ held at temperatures of 250°C and 300°C, short-range order parameters have been determined. Unlike Cu_3Au, the short-range order scattering shows a marked temperature dependence.

* Research sponsored by Office of Naval Research.
[1] M. Hirabayashi, J. Phys. Soc. Japan **6**, 129 (1951).

X2. Ordering and Disordering Processes in Cu_3Au. L. R. WEISBERG,* *Columbia University* (introduced by S. L. Quimby).—Data are reported which describe the isothermal change of Young's modulus with time in a single crystal of Cu_3Au following a sudden change in temperature above, below, and through the critical temperature T_c, when the specimen is initially in one of various states of long- and short-range order. The results are in accord with the kinetic theory of long-range ordering and disordering below T_c proposed by Rothstein[2] and the nucleation theory proposed by Burns and Quimby.[3] Additional supporting data are presented for the latter theory, which is extended in a rough quantitative qnalysis to include the effect of atomic mobility on the formation and growth rates of nuclei. Nucleation, rather than nuclear growth is the prevailing ordering process below 355°C. The data further indicate that the *initial* ordering process in specimens quenched from a temperature above T_c is the establishment of a new short-range order, stable above T_c, and metastable below it.

* Now at the RCA Laboratories, Princeton, New Jersey.
[2] J. Rothstein, Phys. Rev. **94**, 1429 (A) (1954).
[3] F. P. Burns and S. L. Quimby, Phys. Rev. **97**, 1567 (1955).

X3. Kinetics of Long-Range Disordering in Cu_3Au above the Critical Temperature. S. L. QUIMBY AND LEONARD R. WEISBERG, *Columbia University.*—Data are reported which describe the isothermal change of Young's modulus with time in specimens of Cu_3Au which have been subjected to a variety of heat treatments below the critical temperature T_c and then heated to a temperature above T_c and held there. A remarkable feature of the disordering process, previously noted by Siegel,[1] is the rapidity with which its time rate increases with temperature; one degree above T_c it is comparatively slow, fifteen degrees above T_c it is immeasurably rapid. The data suggest that this phenomenon is associated with the dis-

appearance, in the same temperature interval, of the states of metastable equilibrium long-range order which must exist immediately above T_c in this material. The observed variation of the disordering rate at constant temperature with the size of the antiphase ordered domains formed below T_c indicates that disorder diffuses from each domain boundary into the domain.

[1] S. Siegel, J. Chem. Phys. **8**, 860 (1940).

X4. Wrong Bonds *vs* Wrong Atoms in Cu_3Au. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories*.—In the order-disorder literature, attention is often centered on whether an atom is right or wrong with respect to a given assignment of alpha and beta sites even though wrong bonds (AA or BB in place of AB bonds) dominate from energetic considerations. In Cu_3Au, counting bonds shows that 4/3 as much configuration energy is required to form a wrong Cu and a wrong Au when they are not nearest neighbors as when they are (8 *vs* 6 bonds) and that stoichiometric deviation implies only 4 wrong bonds to flip a wrong pair near an excess atom. Measurements of Young's modulus[1] as a function of temperature, have been analyzed and yield 1.3335 for the 4/3 ratio. Nix and MacNair's nonstoichiometric expansion coefficient data[2] support 4 bonds at low and 8 bonds at high temperature (due to wrong triplet "dissociation"). Analysis of Weisberg's relaxation data[1] also indicates the importance of bonds and clusters of wrong atoms in order disorder.

[1] L. Weisberg, Ph.D. thesis, Columbia University.
[2] F. C. Nix and D. MacNair, Phys. Rev. **60**, 320 (1941).

X5. Kinetics of Order-Disorder Transformations in Alloys.* GEORGE H. VINEYARD, *Brookhaven National Laboratory*.—The problem considered is the relating of individual atom movements to the changing state of order of an alloy. A general approach requires considering an infinite array of probabilities for the occupation of various sets of lattice sites by prescribed types of atoms. These probabilities determine all the kinds of order of the lattice, and can be shown to vary according to general equations of motion which are linear and in which the kinetic parameters of atom movements occur as coefficients. The equations can be solved by schemes in which higher order probabilities are approximated by combinations of those of lower order. The vacancy and the direct interchange mechanisms of atom movements lead to similar, but not identical results. That ordering can be likened to simple "chemical" reactions follows from particular approximational schemes, and from those the "chemical" rate constants can also be evaluated. Assuming the vacancy mechanism and employing parameters from diffusion data in Cu and Au, a calculation by these methods gives reasonably good accord with measurements of Burns and Quimby[1] on ordering kinetics of Cu_3Au.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] F. P. Burns and S. L. Quimby, Phys. Rev. **97**, 1567 (1955).

X6. Resistivity *vs* Short-Range Order in Cu_3Au.† A. C. DAMASK,* *Brookhaven National Laboratory*.—Measurements at temperature of the electrical resistivity of Cu_3Au above T_c, the critical temperature, by Burns and Quimby[1] indicate that the resistivity may increase with increasing short-range order. This contrasts with the author's[2] recent findings that in α brass the liquid-nitrogen resistance decreases with increasing short-range order. Therefore, resistance measurements were made at liquid-nitrogen temperature on Cu_3Au quenched from different temperatures above T_c. It was found that for quench temperatures from 395° to 440°C the liquid-nitrogen resistance decreases about 0.5% in an essentially linear manner. The direction of change with short-range order therefore agrees with that observed by Burns and Quimby and is opposite to that observed in α brass. It is planned to extend the measurements to liquid-helium temperature for better comparison of the behavior of the residual resistivity to theory.

† Supported in part by the U. S. Atomic Energy Commission.
* Guest scientist from Frankford Arsenal.
[1] F. P. Burns and S. L. Quimby, Phys. Rev. **97**, 1567 (1955).
[2] A. C. Damask (submitted to J. Appl. Phys.).

X7. The Effect of Short-Range Order on Resistance.* J. B. GIBSON, *Brookhaven National Laboratory*.—The treatment by Murakami[1] of the residual resistance of binary simple cubic solid solutions with short-range order but no long-range order is extended to face-centered solid solutions. For solutions of monovalent atoms, the change in structure changes the effect of short-range order on resistance: in simple cubic structures short-range order decreases resistance from that of the disordered alloy, while in face-centered structures the short-range order increases the resistance above that of the disordered alloy. Damask (see preceding abstract) observed that the residual resistance of Cu_3Au, a face-centered solid solution, decreases with decreasing short-range order in agreement with the foregoing theory. When divalent atoms are added to monovalent atoms as in α brass, the Fermi surface in the Brillouin zone increases in radius. This change of wavelength of electrons with the Fermi energy is sufficient to explain the change in sign in the effect of short-range order on resistance observed by Damask on 30% α brass.

* Under contract with the U. S. Atomic Energy Commission.
[1] T. Murakami, J. Phys. Soc. Japan **8**, 458 (1953).

SATURDAY AFTERNOON AT 2:00

C.I.T., 2315 Engineering

(H. SUHL presiding)

Ferromagnetism, II

Y1. Electronic Specific Heat of the Copper-Nickel System. G. L. GUTHRIE,* S. A. FRIEDBERG, AND J. E. GOLDMAN,* *Carnegie Institute of Technology*.—The simple band theory interpretation of the magnetic properties of copper-nickel alloys suggests that at 60% copper, the 3*d*-band is completely filled. This would require the electronic specific heat to become very low at this composition. The data of Keesom and Kurrelmeyer[1] do not support this interpretation. Since these authors had only one point between 60 and 100% copper, it was considered appropriate to repeat and extend some of these measurements at temperatures between 1.5 and 4.2°K. Our results confirm the extremely high electronic specific heat in the composition range of interest, the presence of an anomaly in the 60% copper alloy and the high value of the Debye θ for this alloy. The heat capacity anomaly is presumed to be of magnetic origin as suggested by the low temperature susceptibility data of Goldman and Arrott.[2]

* Present address: Ford Motor Company.
[1] W. H. Keesom and B. Kurrelmeyer, Physica **7**, 1003 (1940).
[2] J. E. Goldman and A. Arrott, Phys. Rev. **94**, 782 (1954).

Y2. Electronic Specific Heat of γ-Phase Iron Alloys. J. E. GOLDMAN* AND G. L. GUTHRIE,* *Carnegie Institute of Technology.*—The density of electronic states at the Fermi level in iron and its alloys is an important quantity in collective electron theory of ferromagnetism and in the theory of phase stability of alloys. In particular, a comparison of this quantity for iron in the α and γ phase, which is obtained from electronic specific heat data at low temperatures is very desirable. It is impossible to obtain pure iron in the γ phase at low temperatures and one can only estimate this quantity from magnetic and high temperature heat capacity data. It is possible, however, through alloying to retain a face-centered form of iron-rich alloys. We have measured the electronic specific heat of an iron alloy containing 11% manganese and a small amount of carbon which is in the γ phase.[1] The value we obtain for the electronic term is 42×10^{-4} cal/mole °K. This appears to be as high as any metal or alloy previously measured. The implications of this in terms of phase stability of iron and its alloys will be discussed.

* Present address: Ford Motor Company.
[1] We are indebted to Dr. R. J. Weiss of Watertown Arsenal for providing the sample and for discussions.

Y3. Rotational Hysteresis in Ferromagnetic Micropowders. C. P. BEAN AND W. H. MEIKLEJOHN, *General Electric Research Laboratory.*—The rotational hysteresis, i.e., the work required to slowly rotate a specimen 360° in a magnetic field, has been calculated for dilute compacts of ferromagnetic single domain particles with uniaxial anisotropy. The computation is facilitated by the careful calculations on alternating hysteresis in single domain particles presented in the classic paper by Stoner and Wohlfarth.[1] The principal results are that the rotational hysteresis is identically zero for fields less than half the anisotropy field H_A, ($H_A=2K/I_s$), has a value for an aligned aggregate of 2.6 K per cubic centimeter of ferromagnetic material at $H_A/2$, and falls rapidly with increasing fields. It becomes again identically zero for fields greater than the anisotropy field. Experimental measurements have been made on single domain particles of cobalt. Application of the calculations whose results are described above give an unambiguous measure of the distribution of anisotropies present which in principle permit a prediction of the magnetization curve. Due to the simplicity of analysis for anisotropy distribution, this technique is extremely useful in the study of single domain particles.

[1] E. C. Stoner and E. P. Wohlfarth, Trans. Roy. Soc. (London) **A240**, 599 (1948).

Y4. Magnetic Components of the Thermodynamic Functions and Their Significance in Determining Phase Boundaries (I). R. J. WEISS AND K. J. TAUER,* *Materials Research Laboratory, OMRO.*—The thermodynamic functions enthalpy, entropy, and free energy of alpha and gamma iron are determined from existing data. These functions are resolved into their magnetic, lattice, and electronic components on the basis of the additivity of the respective specific heat components. The total magnetic entropy at the melting point approaches $R\ln(2s+1)$ where s is the unparied spin per atom, indicating the validity of the method of separating specific heat components. A comparison of the variation with temperature of the magnetic specific heat (based on long-range order calculations) with the observed curve, shows the existence of short-range order above the Curie temperature. The magnetic enthalpy at the melting point is found to be of the order of RT_c where T_c is the Curie temperature.[1] The free energy function separated into magnetic and nonmagnetic components emphasizes the predominating influence of the magnetic free energy in establishing the regions of stability of the various phases.

* Boston College.
[1] Hofmann, Paskin, and Weiss (abstract Y6 *infra*).

Y5. Magnetic Components of the Thermodynamic Functions and Their Significance in Determining Phase Boundaries (II). K. J. TAUER* AND R. J. WEISS, *Materials Research Laboratory, OMRO.*—The predominance of magnetic free energy is extended to iron-rich regions of iron-manganese alloys to predict the phase boundaries by the following procedure. The free energy of ideal mixing is added to the otherwise unaltered nonmagnetic functions of pure iron to establish the nonmagnetic free energy of the alloys. The magnetic functions of pure iron are modified in accordance with the magnetic properties of the alloy phases to establish the magnetic free energy of the alloy phases. Phase boundaries are determined on the basis of equal chemical potentials of the components in the coexisting phases. Good agreement is obtained with the experimental phase diagram.

* Boston College.

Y6. Magnetic Second-Order Transitions and the Heisenberg Theory of Ferromagnetism. J. A. HOFMANN, A. PASKIN, AND R. J. WEISS, *Materials Research Laboratory, OMRO.*—Using the form of the Heisenberg exchange energy, the magnetic energy of order W is related to the exchange energy parameter J and atomic spin S. J is then related to the critical temperature T_c by making use of recent calculations of Brown and Luttinger[1] and simple Heisenberg theory.[2] This leads to theoretical values for W/kT_c as a function of S. Experimental values for W are obtained from the specific heat curves of Fe, Ni, and Gd on the assumption that the magnetic, lattice, and electronic specific heats are additive.[3] The theoretical variation of W/kT_c with S is in reasonable agreement with experiment. Semiempirical relations between J and S for ferromagnetic transition metals are derived by combining the theroretical relations between J and T_c with the empirical relation between T_c and S of Tauer and Weiss.[4] It appears that J is strongly spin dependent in contrast to the expected constant behavior of the exchange integral in the Heisenberg theory.

[1] H. A. Brown and J. M. Luttinger, Phys. Rev. **100**, 685 (1955).
[2] J. H. Van Vleck, *Electric and Magnetic Susceptibilities* (Oxford University Press, New York, 1932).
[3] R. J. Weiss and K. J. Tauer (abstract Y4 *supra*) in this Bulletin.
[4] K. J. Tauer and R. J. Weiss, Phys. Rev. **100**, 1223 (1955).

Y7. Magnetic Second-Order Transitions and the Van Vleck Theory of Antiferromagnetism. A. PASKIN, J. A. HOFMANN, AND R. J. WEISS, *Materials Research Laboratory, OMRO.*—Van Vleck has shown[1] that the form of the Heisenberg exchange energy can also be used to explain some of the properties of antiferromagnetism. In the Van Vleck theory of antiferromagnetism, the relation of the magnetic energy of order W to J and S is the same as for the ferromagnetic case. We relate J to T_c by making use of the Van Vleck theory and the calculations of Brown and Luttinger[2] based on the Bethe-Peirels-Weiss-Li[3] treatment of antiferromagnetism. This leads to theoretical values for W/kT_c as a function of S. Experimental values for W are obtained from the specific heat curves for a number of antiferromagnetic compounds, based on the assumption of the additivity of the components of the specific heats. The theoretical variation of W/kT_c with S is in good agreement with experiment.

[1] J. H. Van Vleck, J. Chem. Phys. **9**, 85 (1941).
[2] H. A. Brown and J. M. Luttinger, Phys. Rev. **100**, 685 (1955).
[3] Y. Y. Li, Phys. Rev. **84**, 721 (1951).

SATURDAY AFTERNOON AT 2:00

C.I.T., 100 Porter

(J. S. KOEHLER presiding)

Diffusion in Metals

Z1. New Approach to the Kirkendall Effrct. DAVID D. VAN HORN, *Knolls Atomic Power Laboratory.**—Various experimental evidences indicate that in a diffusion couple such as copper-α-brass a flow of vacancies is involved and that these vacancies accumulate in the zinc-rich region. In the analysis of this situation we must consider compositions in terms of site-fractions (N_i^*) rather than chemical fractions (N_i). If we assume that the ternary system copper-zinc-vacancies follows Vegard's law, then the relationship between diffusion coefficients and mobilities is found to be

$$D_i = B_i kT\left(1+\frac{\partial \ln\gamma_i}{\partial \ln N_i}\right)\left(\frac{N_i^*}{N_i}\frac{\partial N_i}{\partial N_i^*}\right)\left(1+\frac{N_i^*}{N_0'}\frac{\partial N_0'}{\partial N_i^*}\right)^{-1},$$

where N_0' is the number of lattice sites per unit volume. It can be shown further, following an analysis similar to that of Darken but allowing for volume changes, that $D=[1+(N_{Zn}^*/N_0')\ (\partial N_0'/\partial N_{Zn}^*)]\ D_{Zn}=[1+(N_{Cu}^*/N_0')\ (\partial N_0'/\partial N_{Cu}^*)]D_{Cu}$ and that in the absence of a volume change there is no marker motion in a Kirkendall experiment. The Kirkendall effect is fundamentally due to volume changes rather than to differences in mobility.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.

Z2. Self-Diffusion of Gold.* B. OKKERSE, *University of Illinois* (introduced by D. Lazarus).—The lattice self-diffusion of gold has been measured in single crystalline specimens of 99.8% and 99.999% purity. The specimens were electroplated with Au^{198}, annealed in vacuum, sectioned, and analyzed following the dry-counting and the solution-counting technique. The diffusion coefficient over the temperature range from 600–950°C can be represented by $D=0.028\exp(-39.200/RT)$ cm²/sec; the average derivation of each point from this relation is 3%, whereas there is no difference in diffusion behavior between the two purities. This result is rather different from the result obtained by Gates and Kurtz.[1] Comparison of both values on the basis of suggested semitheoretical correlations, taking into consideration the most recently reported values for silver, copper, and lead, is inconclusive, due to the qualitative character of these theories.

* Supported in part by the U. S. Atomic Energy Commission.
[1] H. C. Gates and A. D. Kurtz, J. Metals **6**, 616 (1954).

Z3. Self-Diffusion in Silver.* MARCIA MCDONALD, E. SONDER, AND C. T. TOMIZUKA, *University of Illinois.*—In view of the recent interest in the self-diffusion in the silver-rich solid solutions, it is apparent that the accurate redetermination of self-diffusion in pure silver is essential as the point of reference in order to study the effect of alloying. The present work consists of measurements of diffusion coefficients at 8 different temperatures over the range of 944°C to 630°C. Standard sectioning techniques, beta immersion counting and gamma counting method were employed to ascertain the reproducibility of each diffusion coefficient. The results can be represented by $D=0.43\exp(-44{,}200/RT)$ cm²/sec. The value of the activation energy along with the activation energies for the diffusion of Cd, In, Sn, and Sb in silver suggests a reasonably linear relationship when they are plotted as a function of the excess valence of the solute atom. The slope of this line yields a unique value of the screening radius in the neighborhood of 0.57 A if one assumes a simple Thomas-Fermi model.

* Supported in part by the U. S. Atomic Energy Commission.

Z4. Self-Diffusion in Silver-Cadmium Alloys. ALAN SCHOEN, *University of Illinois.**—The self-diffusion of Ag in α-phase Ag-Cd alloys of several different compositions has been studied over a wide range of temperatures, using the tracer-counting lathe-sectioning technique. Measurements of Cd self-diffusion in similar alloys is in progress. Ag has been found to diffuse at a rate which increases with the Cd content of the alloy. The values obtained in this work for D(Ag) in alloys of approximately 30 atomic % Cd are more than twice as large as those recently reported by Hirone *et al.*[1] on the basis of surface-counting measurements. A somewhat smaller discrepancy in the opposite direction appears between Hirone's value for D(Ag) in similar alloys of Ag-Zn and the lathe-sectioning values obtained by Lazarus.[2] The present work is aimed at the systematic study of the concentration dependence of D_0 and Q for self-diffusion of both constituents of Ag-Cd alloys throughout the α-phase region.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Hirone, Kimura, Kitagaki, and Kunitomi, J. Phys. Soc. Japan **10**, 967 (1955).
[2] D. Lazarus, unpublished data.

Z5. Self-Diffusion in Ordered and Disordered Copper-Zinc (β brass).* ALAN B. KUPER, CARL T. TOMIZUKA, AND DAVID LAZARUS, *University of Illinois.*—A pronounced departure from the usual linear $\ln D$ *vs* $1/T$ diffusion relation is found as the alloy orders for both radioactive tracer copper and zinc in 46–48 atomic % Zn single crystals of CuZn. The downward break from linearity begins about 30°C above the transition temperature (T_c) indicating a dependence on short-range order. Both $\ln D$ *vs* $1/T$ curves are closely linear to T_c-100°C at which temperature a slight break to a less steep constant slope is found. Measurements have been made for both tracers down to 290°C (T_c-180°C) and lower for zinc. In the low-temperature range, where the alloy is over 80% long-range ordered, the two slopes are experimentally equal. At all temperatures zinc diffuses faster than copper which, together with the observation of a Kirkendall effect in disordered β brass, indicates that diffusion at all temperatures is via imperfections. Some of the data indicate that diffusion of both metals is faster in the zinc-richer compositions. Assuming the effect to be due primarily to increased binding leads to a monotonic deviation in slope away from linearity. The effect may rather be due primarily to a change in the elastic strain energy involved in a diffusion step, correlating with the observed rapid change of the elastic moduli of the alloy in this temperature range.

* Supported in part by the U. S. Atomic Energy Commission.

Z6. Diffusion of Zinc in Single Crystals of Silver.* A. SAWATZKY, *Franklin Institute Laboratories.*—The diffusion of zinc in silver has been measured in the temperature range from 640°C to 925°C using high specific activity Zn^{65} as a tracer. The data indicate that the diffusion coefficient is given to within two percent by the equation

$$D=0.54\exp(-41\ 700/RT\ \text{cm}^2/\text{sec}).$$

A comparison of these results with those previously reported for the diffusion of Cd in Ag[1] seems to indicate that atomic

size has little effect on the activation energy, but does affect the frequency factor. Certainly, more experimental work will have to be done before this can be considered a valid conclusion.

* This work was supported by the U. S. Atomic Energy Commission.
[1] C. T. Tomizuka and L. Slifkin, Phys. Rev. **96**, 610 (1954).

Z7. Impurity Diffusion in Copper.* C. A. MACKLIET AND D. LAZARUS, *University of Illinois.*—A study is being made of the rates of diffusion of radioactive tracers of Fe, Co, and Ni in pure monocrystalline copper, using sectioning techniques, at temperatures from about 725°C to 1075°C. For a given tracer, log$D$ varies linearly with $1/T$, and, except in the case of Fe above about 950°C, all diffusion rates are slower than that of self-diffusion. Fe diffuses into Cu roughly as fast as does Cu, Co diffuses noticeably more slowly, and Ni still more slowly. The activation energies for diffusion into Cu become progressively larger in steps of roughly 3 kcal/mole as we consider Cu, Fe, Co, and Ni. A study of the diffusion of a Mn tracer into Cu is now underway.

* Supported in part by the U. S. Atomic Energy Commission.

Z8. Tracer-Diffusion of Cu and Zn in 31% α brass. C. TOMIZUKA, J. HINO, AND C. WERT, *University of Illinois.*—The diffusion coefficients of Cu and Zn in a homogeneous alloy of 31% α brass have been measured by a sectioning method. The bulk material was a single crystal made of high-purity Cu and Zn. The diffusion coefficients were determined from the profile of the penetration curve in the usual way. Measurements were made for diffusion anneals from 600°C to 900°C. The data are fitted by the expressions $D_{Zn}'=0.73\ \exp(-40\,700/RT)$ and $C_{Cu}'=0.34\ \exp(-41\,900/RT)$. The activation energies in these expressions are thought to be in error by no more than 1%. From the experimentally determined values of the tracer diffusion coefficients D', we have calculated by the method of Darken the values of D which would be expected for diffusion of Cu and Zn in an alloy containing a concentration gradient. These calculated values do not agree well with the measured values of D recently reported.

Z9. Internal Friction in 31.7% α brass. J. HINO, C. TOMIZUKA, AND C. WERT, *University of Illinois.*—For a number of years attempts have been made to find a way to use damping measurements to calculate diffusion coefficients. This has been done successfully only in interstitial alloys in b.c.c. lattices. Attempts to do this in substitutional alloys have so far not been convincing. The present work is an attempt to find an empirical method to go from damping measurements to diffusion coefficients utilizing the σ peak (the short-range order peak) found in certain alloys. We use a comparison method in which appropriate constants are calculated by matching internal friction data with conventional diffusion measurements at a common temperature of measurement (580°C). The internal friction of an alloy of 31.7% α brass has been measured over the temperature rage 175°C to 580°C. These data are compared with the tracer diffusion measurements reported in the previous abstract. It is concluded that the damping measurements cannot be used to calculate values of D' for either Cu or Zn (these are the tracer coefficients one would measure in a homogeneous alloy). The damping measurements do seem to give reasonable values of D_{Zn}, however (this is the coefficient one would obtain for diffusion of Zn in the presence of a concentration gradient).

Z10. Internal Friction of Cadmium-Magnesium Alloys. JOHN LULAY AND CHARLES WERT, *University of Illinois.*—The internal friction of Cd-rich alloys of Cd and Mg has been measured. A well-defined damping peak is observed which we believe to be the σ peak (i.e., the short-range order peak). It occurs near room temperature for all alloys up to at least 30 atomic % Mg. The activation energy is around 18 kilocalories per mole. The relaxation time is well correlated with some specific heat measurements recently reported.[1] Of most interest in this alloy system is the way in which the magnitude of the peak varies with the Mg content. The ordered structure at 25 atomic % Mg ($MgCd_3$) plays a decisive role in determining the magnitude of the effect; the damping falls nearly to zero for the composition $MgCd_3$. This effect is predicted for the σ peak by a theory of Le Claire and Lomer.[2] The effect is not seen at all in such alloy systems as Ag-Zn and Cu-Zn where no long-range order exists in the α phase.

[1] Coffer, Craig, Krier, and Wallace, J. Am. Chem. Soc. **76**, 241 (1954).
[2] Le Claire and Lomer, Acta Metallurgica **2**, 731 (1954).

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Proceedings of the American Physical Society

MINUTES OF THE WINTER MEETING ON THE WEST COAST HELD AT THE UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES, CALIFORNIA, DECEMBER 28, 29, AND 30, 1955

(Corresponding to *Bulletin of the American Physical Society*, Volume 30, No. 8)

THE 1955 winter meeting on the West Coast of the American Physical Society was held at Los Angeles on Wednesday, Thursday, and Friday, December 28, 29, and 30. Our host for this occasion was the University of Southern California and the occasion was one of a number of events to commemorate the 75th anniversary of the founding of the University. There were thirty-three invited papers, ninety-five contributed papers (that is, ninety-five were published in the Bulletin, and approximately five were either read by title or withdrawn), and three post-deadline papers. Despite the unusually low number of contributed papers, the attendance was very high. There were approximately 570 registrations recorded, which was just a few more than the meeting of the previous year at Berkeley, held in conjunction with the A.A.A.S. One of the high points of the sessions was undoubtedly the symposium on the antiproton, at which Segrè, Weigand, Chamberlain, Murray, and Serber read their papers. As was expected, it was necessary to move to a larger auditorium (the very beautiful Hancock Auditorium), which seats 450 people. Despite the size of the auditorium approximately twenty auditors were forced to stand. The Society owes thanks to Professor C. Eckart for arranging the very interesting session on physical oceanography. This session was also very well attended. The record must show, however, that, since Professor Maurice Ewing was on board the *Vema* at the time, Professor F. Press, of the California Institute of Technology, graciously substituted for him on the program. The other invited programs were arranged by W. P. Dyke, C. Kittel, J. R. Richardson, R. F. Christy, and C. D. Anderson.

As had been predicted, the physical arrangements for the meeting were excellent. Founders Hall, where all the sessions but one were held, is a very beautiful building. It has two large and two small lecture halls, and despite underestimates by a factor of two in the attendance on the part of the local secretary, the building was more than adequate to house the Society comfortably.

The dinner of the Society was held on Thursday evening at the Roger Young Auditorium. It was an excellent affair. It was preceded by a cocktail party open to all, sponsored by the Physics Department of the University. The dinner was excellent, the presiding officer (R. T. Birge) witty, and the principal speaker was President L. A. DuBridge of the California Institute of Technology, who delivered a timely and thoughtprovoking talk on "Physicists Wanted." President Fagg of the University of Southern California was unable to attend and in his place we had a short address of welcome by Educational Vice-President A. S. Raubenheimer. An interesting innovation provided by the weather and the funds of the Publicity Department of the University was coffee served every afternoon just outisde the building where the sessions were held.

To summarize, the meeting was a very profitable and pleasant event for all those who attended. The excellent arrangements and planning were due to the Chairman of the Local Committee, Professor G. Weissler. It is to be hoped that the University of Southern California will re-invite us in the future.

W. A. NIERENBERG
Local Secretary for the Pacific Coast
University of California
Berkeley, California

Errata Pertaining to Abstracts C4, C9, and F5*

C4, by M. H. MacGregor, William P. Ball, and Rex Booth. The headings in Table I should read as follows:

Neutron Bias (Mev)	12.4	10.7	9.0	7.2

C9, by Homer E. Conzett. In line 8, "12°" should read "25°." In line 9, "2.7" should read "1.5." In line 14, "6.1," "1.0," and "3.1" should read "4.2," "1.0," and "3.4," respectively. In line 15, "forward of 20°, continuing to 8°" should read "forward of 30°, continuing to 15°."

F5, by R. G. Summers-Gill. In line 10, instead of "and even parity for this level." read ". . . and odd parity for this level."

* See additional erratum by David O. Caldwell and Yash Pal, Phys. Rev. 100, 1790 (1955).

Proceedings of the American Physical Society

Minutes of the Eighth Annual Gaseous Electronics Conference (Held under the Joint Sponsorship of the Division of Electron Physics, American Physical Society, and the General Electric Research Laboratory at Schenectady, New York, on October 20–22, 1955)

Abstracts of papers presented at this conference have already been printed in *The Physical Review*, Volume 100, pages 1227–1235 (1955). A general review of the conference is to appear in the March issue of *Physics Today*.

The American Physical Society

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Please cut along this line

(To be sent to Professor David Halliday, University of Pittsburgh, Pittsburgh 13, Pennsylvania)

I EXPECT to attend the dinner of the American Physical Society at seven o'clock on Friday evening, March 16. My party will comprise .... persons.

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